International Workshop on Pigeonpeas

Volume 1

International Crops Research Institute for the Semi-Arid Tropics

Proceedings of the

International Workshop on Pigeonpeas

Volume 1

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Contents

Foreword

ICRISAT organized a grain legume workshop in January 1975, soon after the initiation of the Institute's pulse improvement research program. The object was to bring together grain legume workers of the world and to focus attention on the status of pigeonpea and chickpea research. Several aspects of production agronomy, phenology, and quality factors were discussed and ICRISAT scientists proposed a program for improving the genetic potential for yield. After 3 years of work, ICRISAT planned two international workshops, one on chickpea in February 1979 and the other on pigeonpea in December 1980.

The pigeonpea workshop committee sought to provide a forum to review significant research results in pigeonpea improvement, discuss present utilization of pigeonpeas and their potential for the future, identify priorities for further research and development, and recommend a future course of action.

Because of the strong interest of the Indian Council of Agricultural Research (ICAR) in pigeonpea improvement, the Council joined with ICRISAT to organize and cosponsor the International Workshop on Pigeonpeas. The Workshop was held at ICRISAT Center from 15 to 19 December 1980. In all there were 220 participants from 17 countries. ICRISAT's international role in pigeonpea improvement as well as its current plans of research were endorsed. A few eminent scientists were asked to prepare a critique and synthesize the presentations and discussions. This critique and synthesis, presented in a plenary session at the end, will form the basis of future research on pigeonpea by ICRISAT.

The program committee not only invited papers on specific topics to ensure a broad coverage of the subject matter but also opened the doors to voluntarily contributed papers to further widen that coverage. The response was overwhelming, and it was not possible to put together all the papers in one volume. Therefore, these proceedings are published in two volumes: the first includes all the invited papers and discussions and the second volume includes all the contributed papers. We believe these volumes will be a valuable reference work for pigeonpea research scientists.

All the papers were reviewed for technical content prior to the Workshop. ICRISAT scientists who assisted in reviewing the papers were D. G. Faris, R. W. Willey, W. Reed, J. A. Thompson, L. J. G. van der Maesen, R. Jambunathan, N. P. Saxena, L. J. Reddy, Umaid Singh, and J. B. Smithson. I sincerely appreciate their valuable contribution to the Workshop.

Y. L. Nene
Workshop Coordinator

Inaugural Session

Chairman: J. C. Davies **Rapporteur: Y. L. Nene**

search on single crops; our extension system and our infrastructural network are geared towards the consideration of crops by themselves. It is not easy for us to tell the farmer how he should deal in a sensible way with a number of crops together. So perhaps this is a major block to the development of intercropping, and one to which we should address ourselves.

As you know, the CGIAR (Consultative Group on International Agricultural Research) is the organization behind ICRISAT. It is an organization of governments and foundations that came together in 1971 to support agricultural research, on an international basis, with the particular goal of increasing the production of food crops in the developing world. The CG considers pigeonpea a very important crop. In making this determination the CG has been guided by its Technical Advisory Committee (TAC). The TAC initially considered the priorities for various crops in the early 70's and decided that the grain legumes were, at that time, undersupported for research; subsequently additional funds were put into the institutes working on these crops.

In 1978-79, the TAC reexamined its priorities for various crops and again considered that the grain legumes were important crops that needed to be supported by the CG, but generally, that only dry beans as a group merited the same level of priority as the five or six major cereals. Pigeonpea, chickpea, cowpea, and lentils were accorded priority, but not quite on line with rice, wheat, maize, sorghum, and pearl millet. The CG has essentially agreed with the TAC position, accepting the priorities paper, and has continued to accord support to a number of grain legumes, including pigeonpea.

ICRISAT has the mandate within the CG system for work on pigeonpea, although other international agricultural research centers also work upon the crop and use it in their farming systems research. The Governing Board of ICRISAT has given full support to our work. We have about 15 to 20 scientists and an equal number of research technicians and technical assistants working on pigeonpea, and that is a fairly large group in any institute to work on a single crop.

Of course, the ICAR has many more scientists working on pigeonpea, and that is what you would expect in a country this size, with a very real interest in ensuring that there is enough of this important pulse for the people. Many of you are those scientists, and there are many more not here today who work on pigeonpea in one way or another. But I think very few of you are able to work full time on this crop, and perhaps this might be needed in the future if production of pigeonpea in India is to be increased.

Pigeonpea is also an important crop in those 49 countries that I have mentioned earlier. We have here today representatives from several countries besides India who will in the course of the workshop tell you of their work on pigeonpea, from both the low-input and high-input points of view.

Thus we should be able to gain from this conference a good knowledge of the present stateofthe art of pigeonpea improvement and a good look into the future as to what should be done about the crop. We would like to see ICRISAT work to complement work done elsewhere. We have a very good relationship with the ICAR programs; certainly, my impression from talking with scientists who come here for our field days is that they are interested to know what we are doing, generally approve of it, and are happy to see the progress we are making. They are also kind enough to give us ideas for future research on pigeonpea at ICRISAT.

Now we can get from this meeting a much broader perspective, taking a global point of view. We would like to see our work with ICAR continue, particularly as it relates to the production of pigeonpea in India, but we also have a sizable responsibility for the crop in other parts of the world.

We are not here to proselytize — to insist that the crop be grown in areas where it is not proper or not suited — but we are here to help national programs that consider it is, or might be, an important crop. We are here to help and we wantto make sure people make use of this help.

We hope that you will enjoy the Workshop, enjoy our facilities, and enjoy being here in Hyderabad in this lovely weather.

Keynote Address

M. S. Swaminathan*

I recall that at the very first meeting of the Technical Advisory Committee to the Consultative Group on International Agricultural Research, held in June 1971, the need for a more intensive, interdisciplinary, international attack on the barriers to high yields in grain legumes was discussed. A paper prepared by Dr. Roberts of the Rockefeller Foundation, summarizing the work in progress at various national research centers and international institutes, formed the basis for the discussion. It was then decided that since these crops are mostly grown without irrigation in semi-arid areas, it would be appropriate to organize an international institute that would look at the problems of yield improvement in grain legumes, as well as in sorghum and millets, which are grown under similar agroecologicai conditions.

Thus in the Charter of ICRISAT, sorghum and millets as well as pigeonpea and chickpea were originally included under the crop improvement program. It is nearly 7½ years now since ICRISAT came into existence, and I am happy that ICRISAT and ICAR have jointly organized this international workshop to review the current state of research and development in pigeonpea and to suggest ideas for further work during the 1980s.

In the Sixth Five-Year Plan of India, which covers the period 1980-85, particular stress is being laid on thepromotion of pulse production in the country. Pulse crops have always occupied a very important position in our rainfed farming systems, both for meeting the dietary needs of the people and for restoring soil fertility. Unfortunately, the growth rate in the production, area, and yield of pulse crops during the period 1949-50 to 1978-79 has been much below 1% per annum. The area under pulses has varied between 22 and 24 million hectares, and production between 10 and 13 million metric tons (tonnes) in the past.

* Member, Planning Commission, New Delhi, India.

Targets for Pulse Production in the Sixth Five-Year Plan

Production Strategy

The production target during the Sixth Plan has been fixed at 14.5 million tonnes against the base trend production estimate of 11.6 million tonnes.

The major components of the production strategy for achieving this target will be:

1. Introducing pulse crops in irrigated farming systems through a concerted effort in the command areas of all the major and medium irrigation projects. The aim will be to find a place for a suitable grain or fodder legume in the rotation without affecting the main crop of the area. State Land Use Boards will be asked to design the detailed strategy.
2. Improving the productivity of pulse crops in all rainfed farming systems. This will be done through better water conservation and use in every watershed area and through the popularization of a package of improved practices that would help to promote better plant population, appropriate nutrition, and better plant protection and postharvest technology.
3. Bringing additional areas under short-duration varieties during off-seasons or whenever there is adequate soil moisture to sustain a pulse crop.
4. Intercropping wherever possible in all irrigated and unirrigated crop rotations as well as in garden land under three-dimensional crop canopies.
5. Transferring improved technology through appropriate packages of services and public policies.

Thus the strategy involves a systems approach with reference, on the one hand, to the farming system and, on the other, to the production-consumption chain. I am therefore happy to see from the program for this Workshop that topics relating to the production as well as postharvest phases of pigeonpea cultivation will be discussed. The conclusions of the seminar will be of great value to us in preparing the detailed operational blueprints for pigeonpea research and development during the Sixth Plan period.

Being the area of origin of pigeonpea and the principal center of diversity, India has had a virtual monopoly on pigeonpea production in the world so far. However, interest in this crop is growing in many countries because of its multiple uses as a source of food, feed, fuel, and fertilizer. In addition, the pigeonpea plant has been described as a soil plow, because of the improvement that its cultivation brings about in soil structure. Considerable organic matter deposition also takes place in the soil because of the extensive root system. Any improvement brought about in the productivity of this plant would therefore be a great blessing to the rural community.

Research Strategy

Experts who have been working in this field for many years are going to deal with the different aspects of pigeonpea research. I shall not, therefore, try to make a summary of what will be said with authority by individual research scientists. However, there is one aspect of raising the ceiling to the yield of grain legumes that does not so far seem to have received the attention it deserves: this is the whole area of bioenergetics in relation to yield. A Working Group on the biology of yield in grain legumes, constituted by the Technical Advisory Committee of the CGIAR, suggested in 1974 that the only immediately feasible method of raising the ceiling to yield is the introduction of a methodology for the identification of genotypes with better harvest index in favor of grain in the early segregating generations. Attempts to increase the total phytomass production generally have not been successful so far, except in some legumes such as soybean and peas.

We must continue to identify methods of improving both the phytomass production and the share of the grain in the total dry matter. This involves understanding the synergistic interactions between solar energy harvest and cultural energy use. The need for high-protein crops to have the capacity for utilizing greater quantities of nutrients has not received the recognition it requires in yield improvement programs. The input-output ratios with regard to the yield of grains per unit quantity of nutrients supplied will vary with the energy composition of the grain itself. It is common knowledge that advances in calorie production tend to impose a protein penalty, while advances in protein production result in a calorie penalty. We need to find a balance between yield and quality. It is in this context that the efficiency of utilization of atmospheric nitrogen by pigeonpea through the symbiotic system needs more research attention. In general, the nodulation status of this crop has been found to be rather poor in many surveys. While it is easy to demonstrate nodules in the seedling, their visualization at later stages becomes difficult. Perhaps this is connected with the deep-penetrating root system of the crop, so that later nodules are formed rather deep in the soil.

However this may be, it has been a matter of concern that some of the available evidence with the Indian programs goes to show that the succeeding crop may benefit little from the nitrogen that a pigeonpea crop fixes. This has been measured using the response of the succeeding winter cereal in terms of grain yield. Pigeonpea has shown no clear-cut residual effect on the succeeding cereal, unlike most other pulses, which have shown a distinct residual effect. Interestingly, while pure pigeonpea plots showed no residual effects (or less marked ones), plots in which pigeonpea had been parallel-cropped with a short-duration legume such as mung, urd, or cowpea showed distinctly favorable residual effects.

Studies carried out under the All India Coordinated Project on the effect of inoculating pigeonpea seed with rhizobial cultures have given some interesting results. Responses to inoculation, varying from 7 to 51% of control yield, have been observed over 2 years at several locations. The quantum of actual increase in the inoculated crop has varied from 90 to 530 kg/ha. It is to be noted that the latter response was over a reasonable control yield of around 1100 kg/ha. Such response to inoculation was noted not only in new areas such as Ludhiana (Punjab), Hissar (Haryana), and Sardar Krishinagar (Gujarat), but also in traditional pigeonpea-growing areas such as Gulbarga

(Karnataka), Badnapur (Maharashtra), and Jabalpur (Madhya Pradesh).

An intriguing aspect of such response was the apparent lack of any close relation between nodulation (the weight or number of nodules) in the inoculated crop and the increase in grain yield. In some cases, the treatment that gave the maximum response in grain yield at a research center did not differ significantly or even numerically from the noninoculated control, though in other cases the same treatment gave substantial increase in grain yield over control. In some cases, while some strains showed an increase, other equally high-yielding strains showed no difference — or even showed a decrease — from the control in both nodule weight and nodule number. Obviously, nodulation and symbiotic nitrogen fixation are complex processes; perhaps the symbiotic effectiveness of the strains of rhizobia involved differs. Further research on this important topic is needed.

Another interesting aspect of the research findings of the pulse microbiologists is that there appears to be an interaction between the location and strain of rhizobium. As would perhaps be expected in the traditional areas, the strains isolated locally gave the best performance, though there were some exceptions. But even in nontraditional areas, different strains gave the top performance in different years, when the performance was averaged over several varieties. Also, at the same location the best response was obtained with different rhizobial strains when different host genotypes were involved. Interestingly enough, with the same host variety (such as T-21) the best performing strain varied from location to location, and was usually a locally isolated strain, especially in traditional areas of pigeonpea cultivation. All this suggests a complex system of host genotype x rhizobial strain x environment (location x years) interaction. Much more research is needed if we are to fully understand this complex system and manipulate it so that the pigeonpea crop not only meets all its own N requirement from the atmosphere but leaves behind for the succeeding crop a respectable residue of the N so fixed.

I am confident that given the needed in-depth interdisciplinary research effort leading to a wide scrambling of the available genotypes and to the commercial exploitation of hybrid vigor, it should be possible to develop strains characterized by high yields. It is not only absolute yield that is important but per day yield, since pulse crops will have to be fitted into suitable rotations if they are to find a place in all major farming systems. The network of research centers operated by the Indian Council of Agricultural Research and ICRISAT working together should be able to destroy soon the barriers to higher productivity in pigeonpea. I wish the scientists assembled here much success in this challenging task.

Session 1

Cropping Systems

Chairman: Rajat De

Rapporteurs: M. R. Rao
M. Natarajan

Traditional Cropping Systems with Pigeonpea and Their Improvement

R. W. Willey, M. R. Rao, and M. Natarajan*

Abstract

As a sole crop, pigeonpea is relatively inefficient because of its low initial growth rate and low harvest index. The higher harvest index of early genotypes or postrainy-season crops provides more acceptable sole-crop systems, especially as their shorter growing periods can allow other crops to be grown in sequence with the pigeonpea.

Intercropping pigeonpea with more rapid-growing crops such as cereals or legumes can give substantial yield advantages. Vertisol experiments with pigeonpealsorghum at ICRISAT achieved virtually a "full" yield of sorghum with a pigeonpea yield equivalent to 72% of a sole crop. It is suggested that even where double cropping is possible this intercropping system may be a more economic alternative. With the same combination on Alfisols, where double cropping is not possible, intercrop pigeonpea yields equivalent to 40 to 50% of a sole crop represented genuine additional advantages over a sole sorghum system. Pigeonpealgroundnut experiments on Alfisols at ICRISAT gave average yields equivalent to 82% of a sole groundnut crop plus 85% of a sole pigeonpea crop. Evidence is presented to show that pigeonpealsorghum intercropping can give much greater stability of yield than sole cropping, and it is suggested this may also be the case with other pigeonpealcereal and pigeonpeallegume systems.

Pigeonpea is a crop primarily of India, though there are substantial areas in Africa, especially in eastern Africa, where it is probably of much greater importance than commonly recognized. It is also becoming increasingly important in Central and South America and the Caribbean. Though found in a wide range of agroecological situations, its deep-rooting and drought-tolerant character make it an especially useful crop in areas of low and uncertain rainfall and on the lighter soils. It is sometimes grown as a sole crop, but more typically it is grown in relatively complex systems where it is intercropped, or mixed, with other crops. Many of these systems have been described in detail elsewhere (Aiyer 1949; Jodha 1979; Laxman Singh and Shrivastava 1976), and the objective of this paper is to describe only the main features of the more important systems, to identify the role that pigeonpea plays in them, and to suggest some possibilities of improvement. The focus is on seed-production aspects, but in a concluding section the importance of fodder production is briefly discussed.

* Farming Systems Research Program, ICRISAT.

What is a Cropping System?

A cropping system can be defined very simply as a combination of crops in space and time, and the objective of any given system should be to provide the farmer with a high and stable level of returns. In agronomic terms, the systems that best meet this objective are those that make efficient use of the basic resources necessary for plant growth, especially any resources that are limiting. This depends partly on the inherent efficiency of the individual crops that make up the system, and partly on complementary effects between those crops. Our approach is therefore to examine first, the inherent efficiency of the pigeonpea crop itself, and then, how well it complements some of the crops that are commonly grown in association with it.

The Efficiency of Pigeonpea as a Cropping Systems Component

From a cropping systems viewpoint, the efficiency of the pigeonpea crop can be assessed by comparing its growth pattern with that of other crops typical of the drier rainfed areas. In Figure 1a, a comparison is made between a medium-maturity pigeonpea (ICP-1), a sorghum (CSH-6) and a groundnut (Robut 33-1). Each growth curve is averaged over two or three seasons and was obtained from well-managed experiments under relatively good growing conditions at ICRISAT Center.

Compared with sorghum, pigeonpea appears very inefficient, producing only about half the dry-matter yield in just over twice the time. Physiologically, of course, this comparison of a C_3 legume with a C_4 cereal may not be very meaningful. However, the growth rate of the pigeonpea was still low when compared with groundnut, especially in the early stages; final dry-matter yield was about the same, as groundnut, despite a much longer growing period. (Admittedly, Sheldrake and Narayanan, 1979, have emphasized that final yields may underestimate the real growth potential of pigeonpea because of the large amount of leaf fall.)

A majorfactor associated with this slow initial growth of pigeonpea is a poor canopy cover, as illustrated by the patterns of light interception for the same experiments (Fig. 1b). At 30 days after sowing, light interception was still less than 10% and at 60 days it had hardly reached 50%. Peak interception was not achieved until almost 100 days, which was about 45 days later than the sorghum and 25 days later than the groundnut. This slow development of the canopy is of course a well-known feature of pigeonpea, but it is emphasized here because it is an important factor determining the most suitable cropping systems.

A further important feature of pigeonpea —

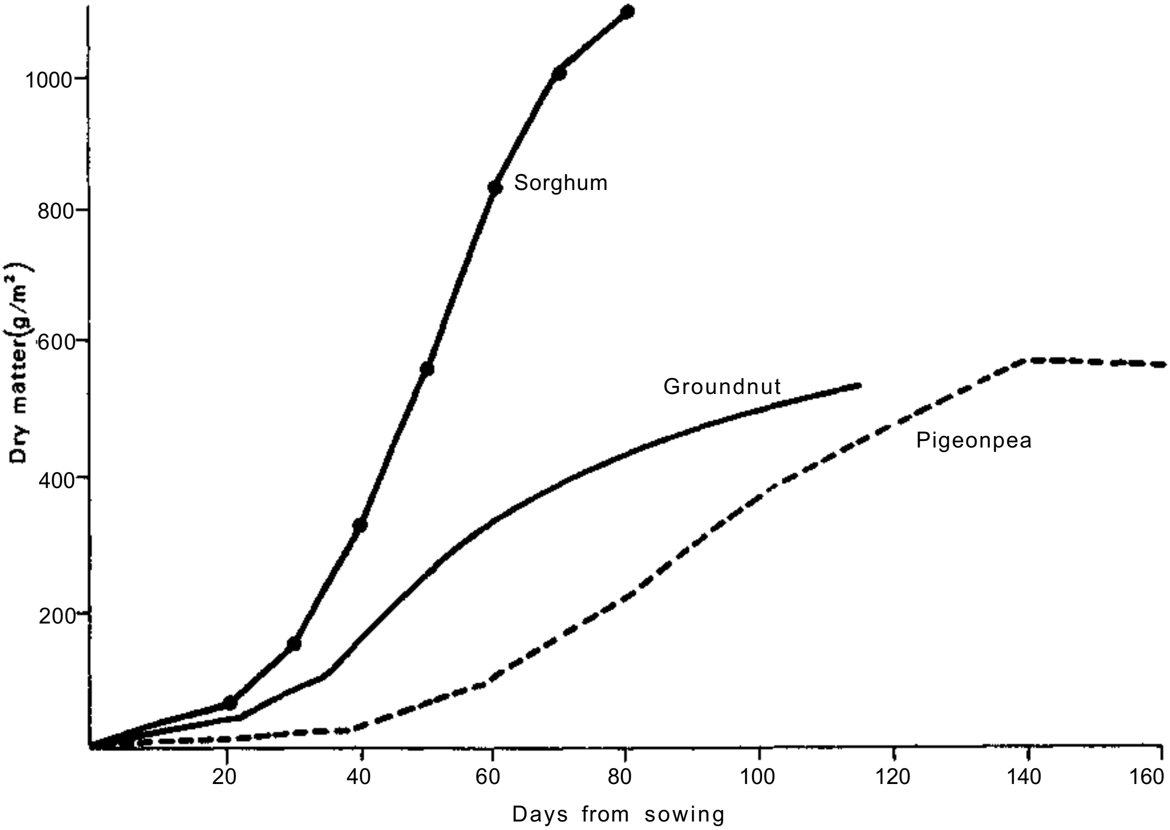

Figure 1a. Dry-matter production by pigeonpea, sorghum, and groundnut as a function of days from sowing.

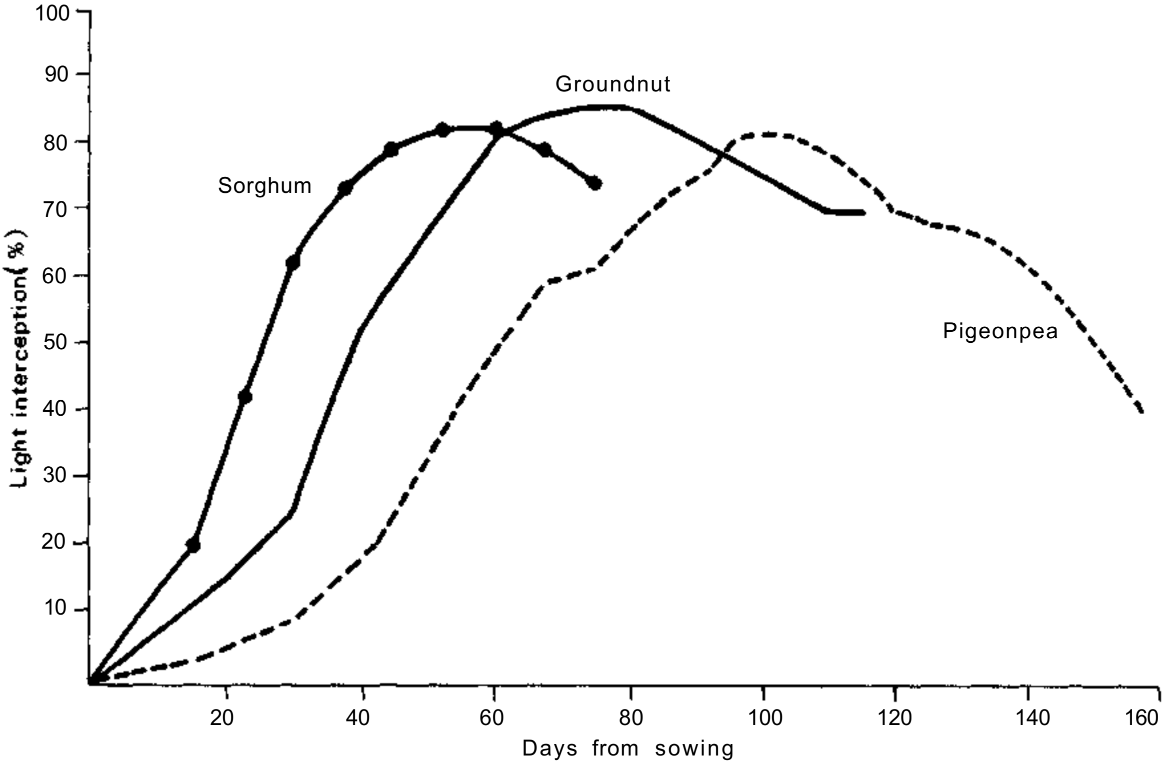

Figure 1b. Light interception by pigeonpea, sorghum, and groundnut as a function of days from sowing.

considered primarily as a seed producer — is its poor harvest index, which is low even compared with most other legumes. In the above experiments it averaged only 22%, and a usual range for medium- to late-maturing genotypes is about 15 to 25% (Ariyanayagam 1975; Sheldrake and Narayanan 1979).

However, a comparison with other crops under relatively good growing conditions does little to indicate the real value of the pigeonpea crop to a farmer. Because of its hardiness, one of its main advantages is its ability to produce someyield u nder conditions too harsh for many other crops. This is particularly true where its relatively long growing period enables it to survive — and yield — on residual soil moisture long after the end of the rainy season (Gooding 1962; Rachie and Roberts 1974). Of course other crops such as castor, cotton or cassava, can do this to some extent, but pigeonpea, being a legume, can also make a valuable contribution to the nitrogen economy of the systems in which it occurs.

Pigeonpea in Sole-Crop Systems

The low initial growth rate and low harvest index of pigeonpea suggest that, as a sole crop, it has some limitations. This section examines some sole-crop systems to see how well these limitations are recognized in farming practice and how far they can be overcome, either by some improvement in the pigeonpea crop itself or by some complementary effects with other crops in the system.

Acland (1976) has described a system in East Africa in which pigeonpea is intercropped in the first year but is then allowed to perennate as a sole crop in subsequent years. This ensuresthat the crop is handled as a sole crop only when it is fully established and can produce a rapid canopy cover at the beginning of the rains. But the pigeonpea crop is more commonly grown as an annual, and Laxman Singh and Shrivastava (1976) have reported that in India, the early-maturing genotypes are the ones com-

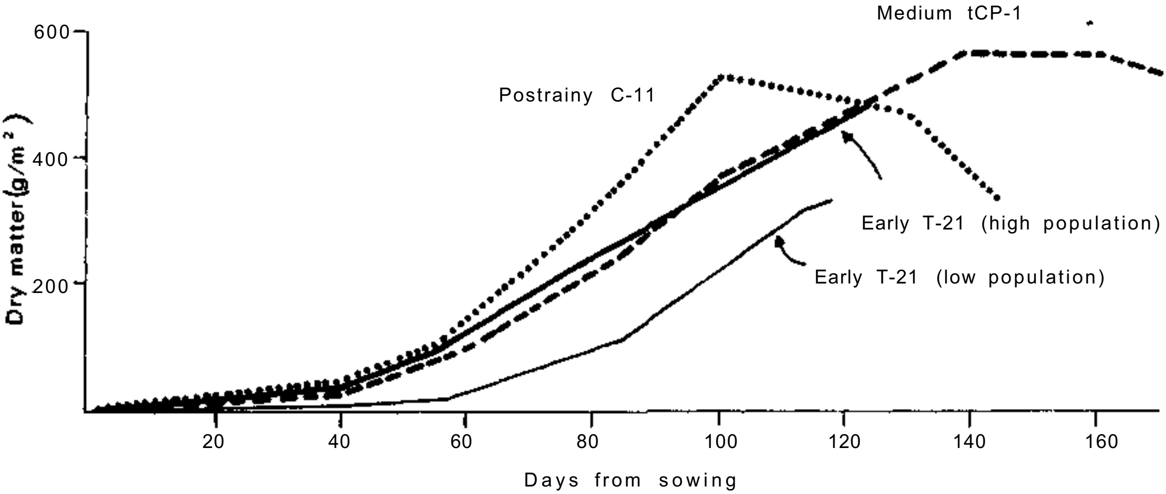

Figure 2. Dry-matter production by early and medium-duration pigeonpea genotypes sown in the rainy season and a medium-duration pigeonpea genotype sown in the postrainy season.

monly grown as sole crops. Figure 2 shows a typical growth curve of such a genotype grown at ICRISAT Center, compared with the growth curve for the medium-maturing ICP-1. In 1974, the early-maturing genotype was grown at an approximate optimum population for medium- or late-maturing genotypes (4.4 plants/m^2) and its growth rate was clearly much poorer than the ICP-1. In 1975, the population was increased by 50% and the rate of growth was then similar to ICP-1, though final dry-matter yield was rather lower because of the shorter growing period. This highlights a very important feature of this early genotype sole-crop system: to achieve a growth rate even comparable to medium-maturing genotypes, the crop must be grown at a much higher plant population. A more advantageous feature of this system, however, is that the harvest index of early genotypes tends to be higher. Sheldrake and Narayanan (1979) quoted an average value of 34% for a number of early-maturing genotypes, compared with only 24% for some medium-maturing genotypes. Clearly, this higher harvest index gives a more acceptable level of efficiency and helps to justify this particular sole-crop system.

But from the cropping systems viewpoint, the most important feature of.the early genotypes is that a similar or slightly lower yield is achieved in a shorter period of time. In a broad sense, therefore, these genotypes are better able to "complement" other parts of the system by providing an increased opportunity for a second crop. There is good evidence of the importance of this in some areas of north India where the availability of improved early-maturing genotypes has made a sole pigeonpea crop competitive with the traditional rainy-season crops of maize, sorghum, and millet. Coupled with the high yield potential of the dwarf wheats, a sequence of pigeonpea followed by wheat has become an accepted and very profitable double-crop system. It has also been observed that the pigeonpea can make use of the phosphate residues from the previous wheat crop (Rao 1975), and in turn it leaves residual nitrogen for the subsequent wheat crop (Pannu and Sawhney 1975). Where irrigation is available throughout the year, it may be possible to take a third crop of summer mung bean, a three-crop sequence that can give a net profit of over Rs. 5000/ha (Saxena and Yadav 1975).

Another sole-crop system, which has long been of minor importance in India (Watt 1908) but which is now receiving considerable attention, is the growing of pigeonpea as a postrainy-season crop. This avoids the wet conditions associated with the rainy season, it gives less incidence of pests and diseases, and it makes better use of the pigeonpea's ability to exploit residual soil moisture. Figure 2 shows the growth pattern of a medium-maturing genotype, C-11, grown in this situation. The main characteristics of this postrainy-season growth pattern are: (1) because pigeonpea is a quantitative short-day plant (Wallis et al. 1975), it is earlier flowering during this season and its maturity period is thus appreciably reduced; (2) with the very high populations that it has been shown to respond to (Sheldrake and Narayanan 1979), its growth rate can be higher than the normal rainy-season crop; (3) because of the earlier flowering, its harvest index is increased; in this particular example it was 37% compared with the 22% of the rainy-season ICP-1 and seed yields were 1170 and 1314 kg/ha, respectively.

Thus this postrainy-season crop appears more efficient than the rainy-season one and, like the earlier maturing genotypes, it also has the advantage of producing good yields in a shorter period of time. Again, therefore, it can be used in a double-crop system, being grown for example after maize, sorghum, or finger millet (AICRPDA 1978) or after paddy, where its higher yield potential compared with the traditionally grown cowpea, urd bean, or mung bean makes it particularly promising. It could also have an important role to play where temperatures are above optimum for the postrainy-season chickpea crop.

One disadvantage of the postrainy-season pigeonpea crop, however, is that to ensure maximum yields it requires early planting, and this may be difficult after most of the rainy-season cereals. Several workers have shown that it can be relay-sown 2 or 3 weeks before the harvest of the previous crop (Khatua et al. 1977; AICRPDA 1976), and experiments over 3 years at ICRISAT have shown that a 20-day overlap with maize or sorghum increased the pigeonpea yield from 732 kg/ha to 988 kg/ha. But relay sowing can present practical difficulties for the farmer and a more realistic solution to this problem would be the provision of cultivars that have a high yield potential despite later sowing.

Pigeonpea in Intercropping Systems

It was emphasized earlier that pigeonpea is commonly grown intercropped with one or more of a wide range of other crops. In India, where it is estimated that 80 to 90% of pigeonpea is intercropped (Aiyer 1949), it is commonly grown with cereals, other legumes, castor, cotton, and occasionally, oilseeds such as sesame. In Africa, pigeonpea is commonly intercropped with maize, sorghum, cowpea, and cassava (Acland 1976), but reports of research are few (Enyi 1973; Nadar 1980; Osiru and Kibira 1979). In Central and South America and the Caribbean, the usual intercrop is maize, but intercropping has had little mention in the literature from these countries (Ariyanayagam 1975; Dalai 1974).

For the purposes of this paper, the more important intercrops can be grouped into three broad categories:

1. the cereals (sorghum, maize, pearl millet, setaria millet, finger millet, rainfed rice, and minor millets);
2. other legumes (groundnut, cowpea, mung bean, urd bean, soybean, and *Phaseolus* bean);
3. the long-season annuals (castor, cotton, and cassava).

The proportions of the crops in a given combination can vary considerably because of such factors as the farmer's dietary preferences, the availability of markets, and the relative values of the crops. Nevertheless, despite the enormous diversity of systems that this creates, some useful generalizations can still be made.

Pigeonpea/Cereal Intercropping Systems

The pigeonpea/cereal intercropping systems are the most frequently occurring ones, and to illustrate the main characteristics of these, the pigeonpea/sorghum combination is considered here as an example. This is one of the commonest of all intercropping systems in India and it also occurs in Africa. As with other pigeonpea/cereal systems, the cereal is usually regarded as the major component; in fact, the traditional Indian objective has been to produce a "full" yield of cereal (i.e., as much as a sole crop) with the pigeonpea serving only to produce some "additional" pulse yield. The farmer achieves this by sowing many rows of cereal and only occasional rows or plants of pigeonpea. While this safeguards the cereal yield, however, it severely limits the pigeonpea contribution.

Figure 3a shows the growth pattern of a sorghum/pigeonpea intercrop obtained from the same experiments that produced the sole-crop patterns described earlier. Pigeonpea was planted in a much higher proportion than in the

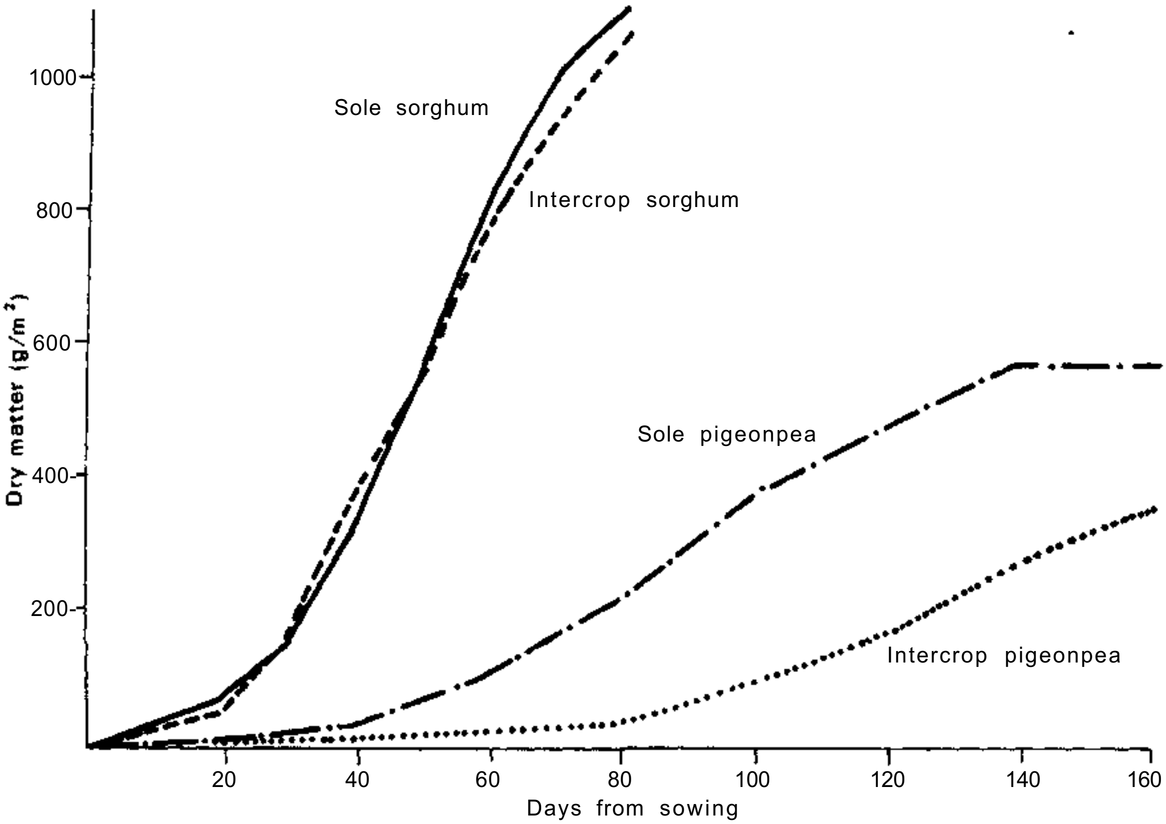

Figure 3a. Dry-matter production by sorghum and pigeonpea in sole and intercrop systems as a function of days from sowing.

farmer's traditional practice, and the intercrop row arrangement was two sorghum to one pigeonpea, on 45-cm rows; the plant population of each crop was the same as its population in sole cropping (180 000 plants/ha for sorghum and 40 000 or 50 000 plants/ha for pigeonpea). The dry-matter accumulation of the intercropped sorghum was only slightly less than that of sole sorghum, and grain yields were similar at 4240 and 4500 kg/ha, respectively. This illustrates the point also made by other workers (Shelke 1977; Krishnamurthy et al. 1978) that by maintaining a high population of sorghum in intercropping the farmer can attain his primary objective of producing a full (or almost full) sorghum yield even when sowing a relatively high proportion of his area to pigeonpea. There is evidence that this can also hold true for other cereals (Chowdhury 1979; Sen et al. 1966; ICRISAT unpublished data).

Figure 3a also shows that because of the emphasis given to the sorghum crop, the pigeonpea component suffered considerable competition during the period of sorghum growth and at sorghum harvest it had accumulated only 16% of the dry-matter yield of the sole crop. After sorghum harvest, however, it was able to compensate to quite a large extent and it finally produced 53% of the sole-crop dry-matter. Even if this intercrop had simply maintained the same harvest index as the sole crop (22%), the additional pigeonpea seed yield would still have represented a considerable improvement over the farmer's traditional situation. In fact, the harvest index was appreciably higher, at 30%, because the sorghum competition reduced early vegetative growth and after sorghum harvest the period of more rapid growth occurred when the reproductive structures were being formed (Natarajan and Willey 1980). Final seed yield from this intercrop pigeonpea was thus a very substantial "additional" 945 kg/ha, or 72% of the sole crop.

The way this pigeonpea/sorghum intercropping system makes much better use of growth resources is typified by the light interception patterns given in Figure 3b. In contrast to the slow canopy cover of the sole pigeonpea, the intercrop gave a very rapid cover, almost as good as sole sorghum. This illustrates particularly well the complementarity between the rapidly establishing sorghum and the much slower establishing pigeonpea. However, Figure 3b also highlights the detrimental effect of sorghum competition on later light interception; immediately after sorghum harvest, the intercropped pigeonpea was intercepting only 25% light and the peak value achieved was only 56%. This suggests that despite the impressive yield advantages of this system, some inefficiencies of resource use may still remain in the later part of the season and there could be scope for yet further improvement.

Some attempts have been made to improve this later efficiency by increasing the population of the intercropped pigeonpea. Figure 4 shows the pooled data of 14 experiments from different sources. Within each experiment, the intercrop pigeonpea yield is given relative to the maximum sole-crop yield, and the intercrop pigeonpea population is given relative to the sole-crop optimum (most of the experiments did not vary sole-crop population and used a single sole treatment at an estimated optimum population of 40 000 or 50 000 plants/ha). There was a consistent, though small, response up to populations well above the sole-crop optimum; at exactly twice the sole-crop optimum, the estimated yield was 68% of the sole-crop yield, whereas at the sole-crop optimum it was only 59%. Alternate rows of sorghum and pigeonpea have also been tried to give a better distribution of the pigeonpea population. This has given increases in pigeonpea yield but these have been largely offset by reduced sorghum yield (Rao and Willey 1980b); this row arrangement could be acceptable, of course, where the sorghum assumes rather less importance in the systems.

It must be explained, however, that the mean yield advantages quoted from the experiments in Figure 3 were obtained on deep Vertisols,

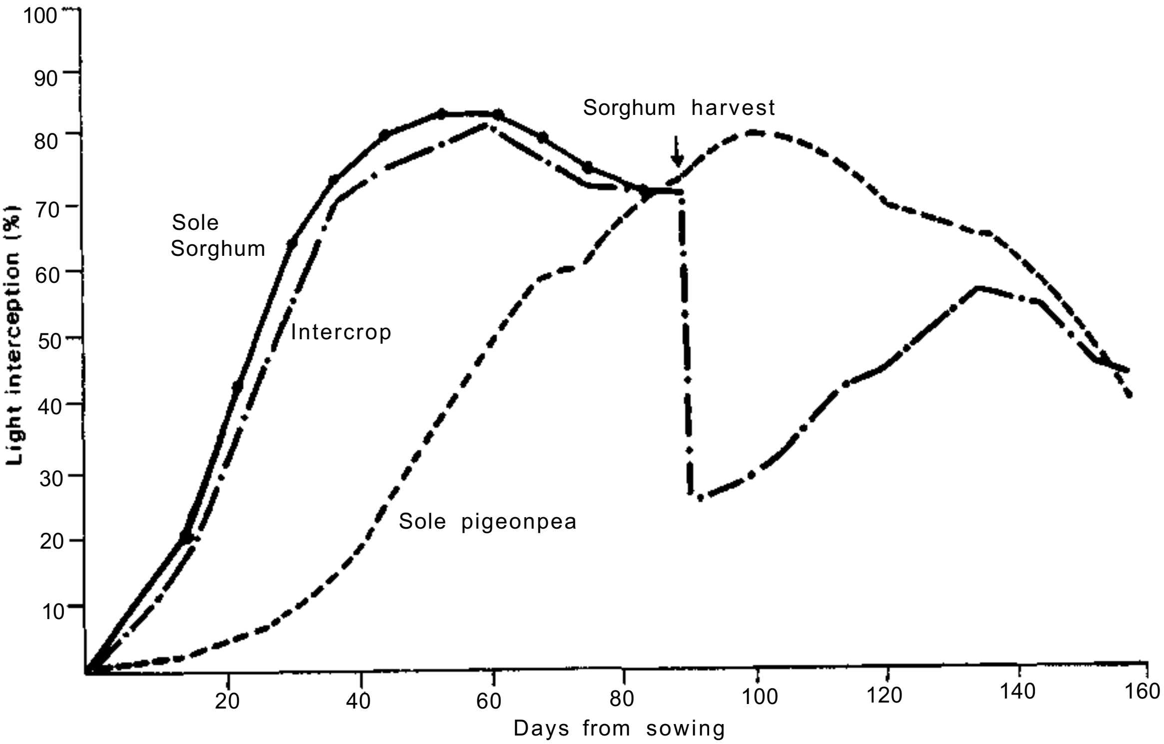

Figure 3b. Light interception by sole pigeonpea, sole sorghum, and combined intercrop as a function of days from sowing.

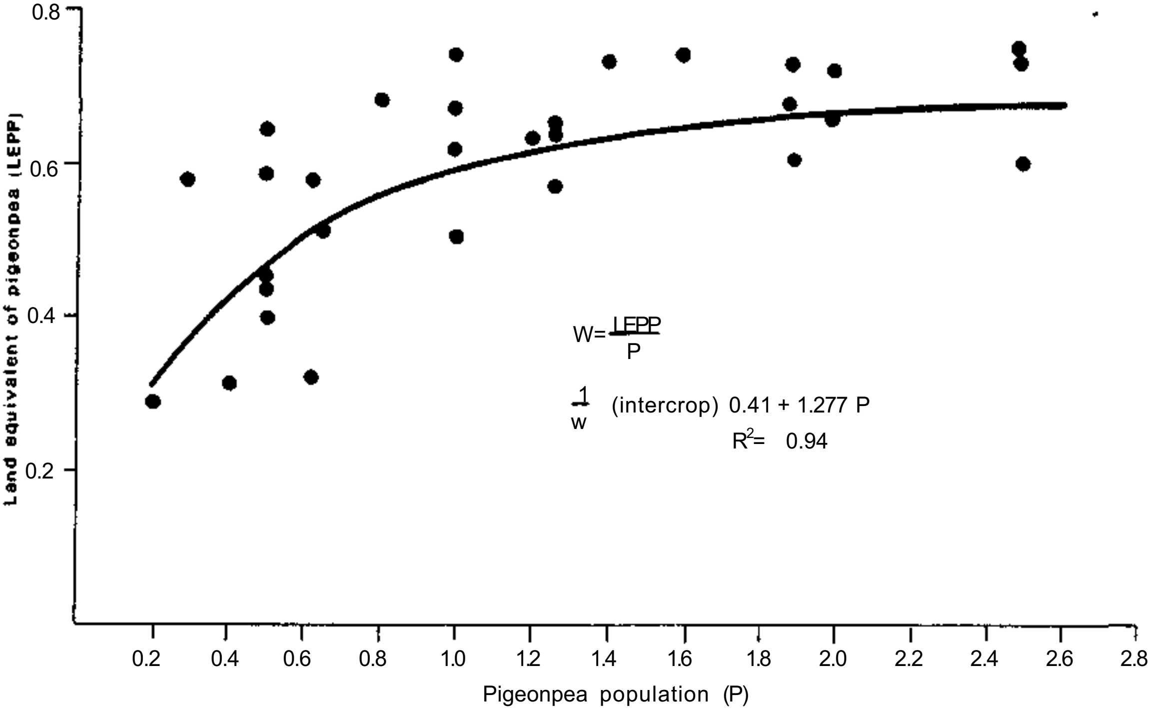

Figure 4. Effect of relative plant population on the relative yield of pigeonpea intercropped with sorghum (Sources: Shelke 1977, Tarhalkar and Rao 1978, and ICRISAT unpublished data).

which have good moisture-holding capacity and are therefore especially favorable for pigeonpea growth after sorghum harvest. At first sight, such conditions might also seem especially f avorabl e for use of the intercropping system in preference to sole cropping. But with theadvent of earlier maturing cereal genotypes, such conditions now offer the farmer the possibility of two sequential crops. Indeed Jodha (1979) reported that with the introduction of early-maturing sorghum hybrids, Indian farmers often forsake their traditional intercropping patterns to grow sole sorghum in the rainy season and a second crop in the postrainy season. These alternative systems have been compared at ICRISAT and small plot experiments indicate that if sequential sole-crop systems can be handled efficiently, with the second crop being sown immediately afterthe harvest of the first, they may give slightly higher returns than a pigeonpea intercropping system. But in farming practice one of the advantages of the intercropping system is that both crops are sown at the beginning of the rains, thus avoiding possible difficulties in trying to establish a second crop at the end of the rains. It is of particular interest, therefore, that in operational-scale trials at ICRISAT there has been an average gap of 7 to 10 days between harvest of the first crop and sowing of the second in sequential systems; furthermore, when the costs of establishing the second crop have been taken into account, the intercropping system has proved to be more profitable (Ryan et al. 1980).

This possibility of alternative systems under conditions of good moisture supply points to an important conclusion: pigeonpea intercropping may play its major role in conditions of poorer moisture supply, despite the lower intercrop pigeonpea yields and theapparently loweryield advantages compared with sole crops. For example, on the Alfisols at ICRISAT the ICP-1 genotype when intercropped with sorghum has given an average yield of about 40 to 50% of its sole crop; but inasmuch as a farmer may have no alternative means of using the residual moisture after sorghum harvest in this situation (i.e., he cannot grow a second crop), this may represent a more genuine benefit of intercropping than the 60 to 70% that this same genotype has given on Vertisols.

Briefly considering the intercropping of pigeonpea with other cereals, there is now a wealth of evidence that the general pattern of competition and yield advantage is very similar to that described for sorghum. Maize especially seems to follow the same pattern, though it has been suggested (Krantz 1979) that two possible advantages of the maize are its nonratooning nature and thefact that, to help reduce competition on the pigeonpea, its top can be broken over sometime before harvest (as is commonly practiced with maize/beans intercropping in South and Central America). Variations in the general pattern occur with differences in the relative competitive ability of the cereal, and this is dependent mainly on the cereal height and maturity (Rao and Willey 1980a). The short, early-maturing cereals such as the millets seem least likely to suffer any depression in their own yield because their rapid growth makes them very competitive and they are harvested before the pigeonpea offers much competition. Moreover, these short early cereals also allow greater pigeonpea yield because of the shorter period of cereal competition and the longer period for compensatory growth after cereal harvest.

This effect of height and maturity of the cereal raises the important point that the early, short, high-yielding genotypes of cereals that have been selected for efficient sole cropping are also ideally suited to this pigeonpea/cereal intercropping system. In addition to much higher cereal yields, higher pigeonpea yields are also possible, and thus much greater intercropping advantages can be achieved than with the traditional tall, late cereals. Consequently, the change to sole cropping so commonly associated with the introduction of these new genotypes (Jodha 1979) should only occur if there is some other change in the system (e.g., a change to double cropping) that results in a greater overall benefit than intercropping; the change to sole cropping should not occur simply because the new genotypes are seen to be part of some new technology in which intercropping is thought to have no part.

Pigeonpea/Legume Intercropping Systems

The pigeonpea/legume combinations are second in importance after the pigeonpea/cereal ones. In Africa, the commonest legume intercrop is cowpea, but no experiments on this have been reported from that region. In India, the commonest legume intercrop is groundnut, though cowpea and mung bean also occur quite frequently.

Considering the pigeonpea/groundnut combination first, no detailed growth studies have been reported, but the sole-crop data given earlier illustrate that in the early stages the groundnut has a more rapid rate of growth (Fig. 1a) and a better canopy cover (Fig. 1b) than the pigeonpea. As an intercrop, therefore, groundnut can help to make better use of resources in the early growth stages. This temporal complementarity may not be quite as marked as with the cereal intercrops, but an important additional factor may be the ability of groundnut to make efficient use of low light levels (Reddy and Willey 1980). The groundnut is also much more susceptible than the cereals to pigeonpea competition, but it does allow a much increased pigeonpea yield (Rao and Willey 1980a).

In farming practice in India, the pigeonpea/groundnut combination is grown in more varied proportions than the pigeonpea/cereal combinations. Quite often the groundnut is the major component, probably reflecting its importance as a cash crop, and the planting pattern then tends to be many rows of groundnut with only occasional rows of pigeonpea. But also quite common are only a few rows of groundnut interspersed with more frequent rows of pigeonpea.

Early studies on the predominantly groundnut situation (8-10 rows groundnut: 1 row pigeonpea) showed that although high groundnut yield is maintained, the pigeonpea contribution is very small (John et al. 1943; Seshadri et al. 1956). More recently, slightly higher proportions of pigeonpea (6 rows groundnut: 1 row pigeonpea) have still maintained almost a full groundnut yield but have increased pigeonpea yield to more than 30% of a sole-crop yield (Veeraswamy et al. 1974; Appadurai and Selvaraj 1974). Studies at ICRISAT over several locations on Alfisols have examined even greater proportions of groundnut. Pigeonpea was grown in 135-cm rows with five very close rows (22.5 cm) of groundnut between. Plant populations of each crop were at the level of their sole-crop optimum, and yields averaged 82% of the sole groundnut crop plus 85% of the sole pigeonpea crop, i.e., there was a yield advantage of 67% over sole cropping.

These recent data emphasize that this combination can give good yield advantages over a wide range of crop proportions. Thus thefarmer has considerable flexibility for adjusting the balance of the two crops to suit his specific requirements. However, greatest advantages seem to be obtained when there is a substantial pigeonpea contribution and this situation may become increasingly accepted because of the good returns from pigeonpea.

Considering the other legume intercrops, these seem most often regarded as minor components in predominantly pigeonpea systems. Thus typical planting patterns are relatively close plantings of pigeonpea with only a few intervening rows of the other legumes. But even as minor components, all these legumes are probably able to give some worthwhile temporal complementarity with the pigeonpea. Experiments have concentrated on the predominantly pigeonpea systems and have shown that useful "additional" yields of other legumes can be achieved with little or no effect on the pigeonpea; for example, mung has produced additional returns equivalentto 15 to 51% of the value of the pigeonpea crop; urd bean 21 to 40%; and soybean 15 to 42% (Giri and De 1978; Kaul et al. 1975; Mahatim Singh et al. 1979; Saraf et al. 1975; Saxena and Yadav 1979; Sharma et al. 1973; Tiwari and Bisen 1975).

As a final comment on the pigeonpea/legume systems, there seems no reason why their residual benefits should be any less than from sole legumes, though no studies on this have been reported. In fact, it would seem reasonable to expect better residual benefits from the intercropping systems because of the higher yields that they can produce.

Pigeonpea/Long-Saason Annual Intercropping Systems

Pigeonpea is intercropped occasionally with cassava in Africa and quite commonly with cotton or castor in India. However, almost no research has been reported on these combinations. One experiment on pigeonpea/castor has suggested that this combination offers little or no yield advantage (Rao and Willey 1980a), and this is what would be expected from the very similar growth patterns of these crops. Thus these combinations may well illustrate that farmers do not always achieve higher yields from their traditional intercropping systems. Because all these long-season annuals occupy similar agroecological niches, they may be grown as intercropping combinations simply because farmers find it convenient to grow them together. Of course, there may be other advantages that have not yet been recognized, such as better control of pests and diseases, or greater yield stability.

Pigeonpea in Three-Crop Intercropping Systems

It has been suggested elsewhere (Willey 1979) that introducing a third crop into an intercropping system may give only a limited yield response, because as more crops are added, the scope for further complementary effects progressively diminishes. However, where a long-season crop such as pigeonpea is involved, the addition of a third crop can be worthwhile. In some early ICRISAT experiments in which various intercrops were added between 150-cm rows of pigeonpea, the addition of only groundnut gave a yield advantage of 41%, but the further addition of a setaria millet increased this to 66% (Rao et al. 1977). More recently, an experiment on a Vertisol at ICRISAT examined the effect of adding chickpea in the gaps left after harvesting maize from a maize/pigeonpea intercropping system. This gave an additional 528 kg of chickpea (equivalent to 36% of a sole crop) without causing any yield reduction in the pigeonpea, and monetary returns were higher than the best double-crop system of maize followed by chickpea.

Some Further Comparisons between Sole and Intercropping Systems

It was emphasized earlier that the objective of any cropping system should be to produce not only high, but also stable, yields, and there has long been a traditional belief that intercropping may confer greater yield stability than sole cropping. Rao and Willey (1980b) have recently examined stability of sole and intercropping systems across 94 experiments of pigeonpea/

sorghum carried out at various locations across India, covering a wide range of soil types, with rainfall varying from 408 mm to 1156 mm. Yields of the sole crops ranged from 310 to 6200 kg/ha for the sorghum and 274 to 2840 kg/ha for the pigeonpea. Several analyses of stability were examined, but the one considered most meaningful from the farmer's viewpoint was estimation of the probability of crop "failure" as measured by monetary returns falling below any given "disaster" level of income. On this basis, pigeonpea/sorghum intercropping "fails" less often than either sole crop, or a "shared-sole" system where a farmer grows some of each sole crop (Fig. 5). Taking an example disaster level of Rs. 1000/ha, sole pigeonpea fails 1 year in 5, sole sorghum 1 year in 8, shared-sole 1 year in 13, but intercropping only 1 year in 36.

A commonly suggested cause of greater yield stability in intercropping is that if one crop fails, or grows poorly, the other crop can compensate to some extent. This mechanism assumes that the crops have rather different responses to the environment and that there are times when one crop is more likely to fail than the other. When pigeonpea is intercropped with a much earlier maturing crop, there seems a particularly good possibility of complementary environmental responses that might increase stability. Thus the pattern of greater stability described for the pigeonpea/sorghum combination seems likely to be repeatable for other pigeonpea combinations with earlier maturing crops. For the pigeonpea combinations with castor, cotton, or cassava, where growth patterns and environmental responses are not so different, the likelihood of greater stability because of this particular mechanism seems much less.

A second stability mechanism widely be-

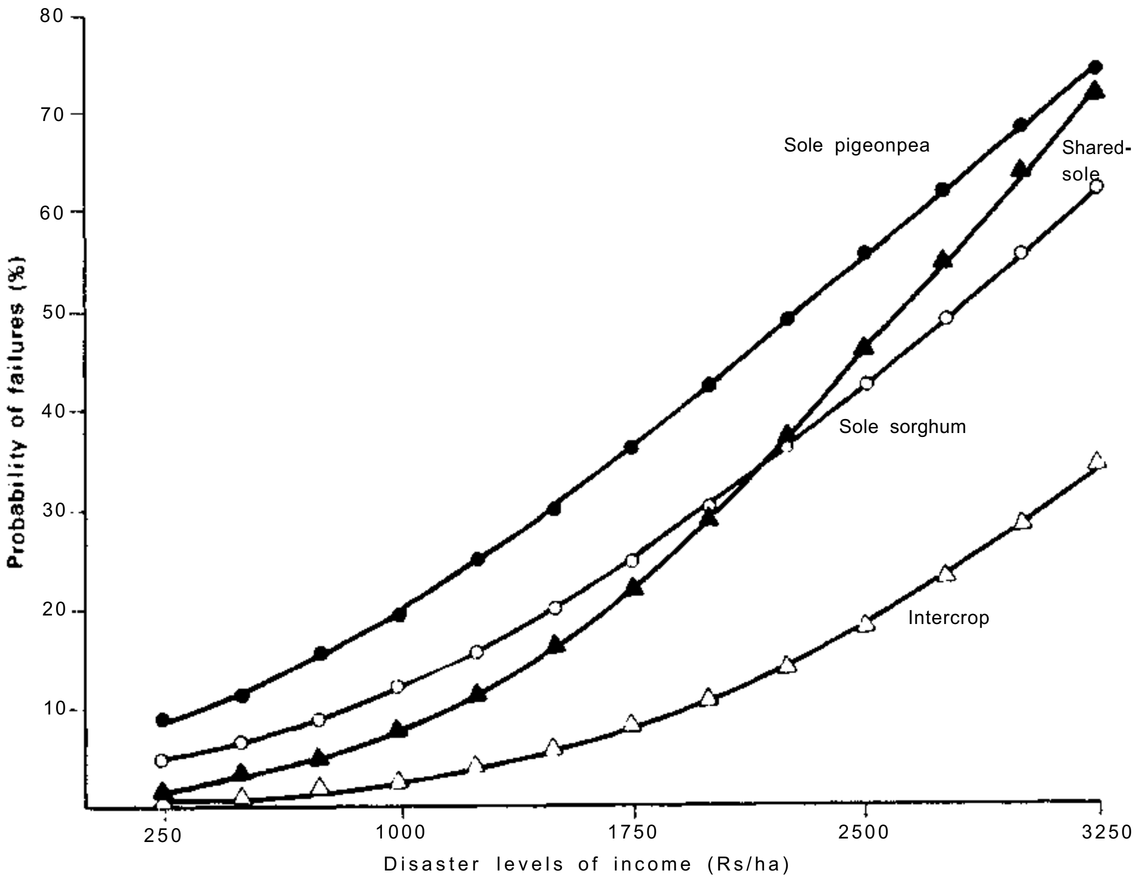

Figure 5. Probability of failure for sorghum and pigeonpea in different cropping systems at given disaster levels of income.

lieved in is that under stress conditions intercropping can give a relatively greater yield advantage, resulting in less yield depression than sole cropping. This has probably helped to foster the belief that intercropping is only appropriate under poor growing conditions and that it has no place where high-cost inputs are used. The most outstanding example is the pigeonpea/cereal combination when a farmer begins to use nitrogen fertilizer on his cereals, a change that usually goes hand-in-hand with a changeto a new, high-yielding cereal genotype. Again there seems to be a belief that to get the best out of both fertilizer and new genotype, the farmer should also change to a sole cereal crop. Admittedly, the relative advantages of intercropping compared with sole cropping can be less at high nitrogen levels, because on average the intercrop cereal does not quite achieve the full yield of its sole crop, and the increased competitive ability of the cereal can slightly reduce the pigeonpea yield (Rao and Willey 1980b; and Rego 1979). But even this reduced intercrop advantage can still far exceed the additional benefits achieved from the slightly more efficient nitrogen response of the sole cereal. As an example, a sorghum producing 4000 kg/ha as a high-input sole crop at optimum level of nitrogen can be expected to produce at least 3500 to 3600 kg/ha as an intercrop. With present price structures, this sacrifice of 400 to 500 kg/ha of sorghum grain because of intercropping would be offset by as little as 175 to 200 kg/ha of additional pigeonpea; even under conditions of poor residual moisture, the expected pigeonpea yield would be two or three times this, and under good conditions it would be much more.

Incidence of Pests, Diseases, and Weeds

Comparisons of sole and intercropping systems also raise questions on the incidence of pests, diseases, and weeds. Other papers will discuss specific aspects of this later in this workshop, so we will summarize briefly here. Referring again to traditional beliefs, it is commonly stated that the incidence of pests and diseases is lower in intercropping than in sole cropping. While there is evidence across various intercrop combinations that this can be so, it must be recognized that this is an extremely complex situation, in which adverse effects can also occur. To take two contrasting examples, there is recent — though tentative — evidence at ICRISAT that a sorghum intercrop may reduce the incidence of pigeonpea wilt; in contrast, a later paper will showthat a sorghum intercrop may aggravate a major pest of pigeonpea. The pest and disease situation, therefore, is an area in which generalizations are not only difficult but also misleading, and much more detailed work in specific situations is required.

The question of weeds is more straightforward. Because of the poor canopy cover and slow growth of the pigeonpea in the early stages, a sole crop is especially susceptible to weed competition. Thus a faster growing intercrop not only gives additional yield benefits, but also reduces the need for weeding (Shetty 1979).

Selection of Genotypes for Different Cropping Systems

A final factor to be considered is the need for selecting genotypes specifically suited to the different systems. The intercropping system is again the major concern here. In the past, genotypes destined to be grown mainly in intercropping have been selected entirely in sole cropping. The extent to which this sole-crop selection is acceptable will depend in large measure on what intercrop the pigeonpea is to be grown with, and possibly the balance of competition between the crops. If it is to be grown as the dominant component with other legumes, a situation in which it suffers relatively little competition and grows not unlike a sole crop, then sole-crop selection might well be acceptable. But a later paper at this workshop (Rao et al. these Proceedings) will suggest that if pigeonpea is to be grown with the cereals, where it suffers considerable competition, the efficiency of selection will be improved if at least the later stages of selection are carried out in an appropriate intercropping system.

Fodder and Ratoon Systems

Although seed production is usually the primary objective of traditional systems, the associated large amount of vegetative material can also provide valuable fodder. Consequently, where fodder is known to be important, care should be taken that improved seed-production systems do not have an adverse effect on fodder production. As examples, the sole-crop systems using early genotypes or postrainy-season sowing (described earlier) both produce relatively lower amounts of fodder because of lower total dry matter and higher harvest index. In many farming situations this would have to be taken into account in assessing the overall value of these systems. The lower harvest index of the pigeonpea when intercropped with a cereal represents rather a different situation, however. The improved system described earlier produces considerably more pigeonpea than the farmer's traditional system; thus, far from indicating lower fodder yields, the lower harvest index indicates that the increases in fodder yield are not quite so high as those in seed yield.

Additional fodder yields can be obtained by various ratooning systems where there is sufficient moisture for an extended period of growth. Most commonly, this is regrowth after a seed harvest but an alternative can be an early fodder cut, which is then ratooned for seed (Killinger 1968). Averaged over 2 years at ICRISAT, the genotype C-11 gave no decrease in seed yield after a 60-day fodder cut, and only a 10% decrease after an 80-day cut; genotype BDN-1 gave decreases of only 13% and 16% for the same treatments (unpublished data). But two problems with this system are, first that there is a much greater risk of losing the seed crop because of insufficient moisture late in the season and, second, fodder produced early in the rainy season may not be so highly valued as that produced in the dry season after a normal seed harvest. Under favorable moisture conditions it can be possible, of course, to follow a normal seed crop with a ratoon seed crop. Sharma et al. (1978) reported that for some early genotypes the ratoon seed yield could be as high as the first crop, butf or some medium to late genotypes, yields ranged from only 20 to 60% of the first crop. An extremely promising ratoon system for seed production has also been recently reported from Australia (Wallis et al. 1979).

References

ACLAND, J. 1976. East African crops. London: Longmans.

AICRPDA. 1976. Progress Report of the All India Coordinated Research Project for Dryland Agriculture, Bhubaneswar, Orissa, India.

AICRPDA. 1978. Progress Report of the All India Coordinated Research Project for Dryland Agriculture, Bhubaneswar, Orissa, India.

AIYER, A. K. Y. N. 1949. Mixed cropping in India. Indian Journal of Agricultural Sciences 19: 439-543.

APPADURAI, R., and SELVARAJ, K. V. 1974. A note on groundnut-redgram mixture in lower Bhawani Project area. Madras Agricultural Journal 61: 803-804.

ARIYANAYAGAM, R. P. 1975. Status of research on pigeonpeas in Trinidad. Pages 131-147 *in* Proceedings, International Workshop on Grain Legumes. ICRISAT, 13-16 Jan 1975, Hyderabad, India.

CHOWDHURY, S. L. 1979. Recent studies in intercropping systems on the drylands of India: some thoughts, some results. Presented at the International Workshop on Intercropping. 10-13 Jan 1979, ICRISAT, Hyderabad, India. Proceedings in preparation.

DALAL, R. C. 1974. Effects of intercropping maize with pigeonpea on grain yields and nutrient uptakes. Experimental Agriculture 10: 219-224.

GIRI, G., and DE, R. 1978. Intercropping of pigeonpea with other grain legumes under semi-arid rainfed conditions. Indian Journal of Agricultural Sciences 48(11): 659-665.

GOODING, H. J. 1962. The agronomic aspects of pigeonpeas. Field Crop Abstracts. 15: 1-5.

JODHA, N. S. 1979. Intercropping in traditional farming systems. Presented at the International Workshop on Intercropping. ICRISAT, 10-13 Jan 1979, Hyderabad, Indi8. Proceedings in preparation.

JOHN, C. M., SESHADRI, C. R., and BHAVANISAGAR RAO, M. 1943. Mixed cropping of groundnut. Madras Agricultural Journal 31: 191-200.

KAUL, J. N., SEKHON, H. S., and DAHIYA, B. S. 1975. Intercropping studies with pigeonpea. Indian Journal of Genetics and Plant Breeding. 35: 242-247.

KHATUA, K. B., SAMAL, K. M., and GHOSH, P. C. 1977. Cropping pattern for rainfed highland. Journal of Research of Orissa University of Agriculture and Technology 7(1): 18-24.

KILLINGER, G. B. 1968. Pigeonpea (*Cajanus cajan* [L] Druce) - A useful crop for Florida. Proceedings, Soil and Crop Science Society of Florida 28: 162-167.

KRANTZ, B. A. 1979. Intercropping on an operational scale in an improved farming system. Presented at the International Workshop on Intercropping. ICRISAT, 10-13 Jan 1979, Hyderabad, India. Proceedings in preparation.

KRISHNAMURTHY, CH., CHOWDHURY, S. L., and ANDERSON, D. T. 1978. Intercrop systems with particular reference to pigeonpea-sorghum — present practices and new recommendations. Presented at the National Symposium on Intercropping of Pulse Crops in India. Indian Agricultural Research Institute, 17-19 July 1978, New Delhi, India.

LAXMAN SINGH and SHRIVASTAVA, M. P. 1976. Cultivation systems and varietal adaptations of pigeonpea *(Cajanus cajan* [L] Millsp.) in Madhya Pradesh. Indian Journal of Genetics and Plant Breeding 36: 293-300.

MAHATIM SINGH, KALYAN SINGH, SINGH, R. K., and SAUMITRA, B. S. 1979. Effect of intercropping on growth and yield of pigeonpea. Indian Journal of Agricultural Sciences 49(2): 100-104.

NADAR, H. M. 1980. Intercropping under marginal rainfall conditions in Kenya. Presented at the Second Symposium on Intercropping in Semi-Arid Areas. 4-7 Aug 1980, Morogoro, Tanzania.

NATARAJAN, M., and WILLEY, R. W. 1980. Sorghum-pigeonpea intercropping and the effects of plant population density. 1. Growth and yield. Journal of Agricultural Science (Cambridge). In press.

Osmu, D. S. O., and KIBIRA, G. R. 1979. Sorghum/pigeonpea and finger millet/groundnut mixtures with special reference to plant population and crop arrangement. Presented at the International Workshop on Intercropping. ICRISAT, 10-13 Jan 1979 Hyderabad, India. Proceedings in preparation.

PANNU, J. S., and SAWHNEY, J. S. 1975. Effect of arhar on the nitrogen requirements of the succeeding wheat in an intensive rotation. Indian Journal of Genetics and Plant Breeding 36: 253-256.

RACHIE, K. O., and ROBERTS, L. M. 1974. Grain legumes of the lowland tropics. Advances in Agronomy 26: 32-44.

RAO, M. R. 1975. Direct, residual and cumulative effect of phosphate in maize-wheat and arhar-wheat cropping systems. Ph.D. Thesis. Indian Agricultural Research Institute, New Delhi, India.

RAO, M. R., and WILLEY, R. W. 1980a. Preliminary studies of intercropping combinations based on pigeonpea or sorghum. Experimental Agriculture 16: 29-40.

RAO, M. R., and WILLEY, R. W. 1980b. Evaluation of yield stability in intercropping: studies on sorghum/pigeonpea. Experimental Agriculture 16: 105-116.

RAO, M. R., REGO, T. J., and WILLEY, R. W. 1977. Plant population and spatial arrangement effects in monocrops and intercrops in rainfed areas. Presented at the Seminar on Dry Farming. Institute of Agricultural Technologists, 16 Apr 1977, Bangalore, Karnataka, India.

RAO, M. R., WILLEY, R. W., SHARMA, D., and GREEN, J. G. 1981. Pigeonpea genotype evaluation for intercropping. Physiology and Agronomy, Volume 2, these Proceedings.

REDDY, M. S., and WILLEY, R. W. 1980. Growth and resource use studies in an intercrop of pearl millet/groundnut. Field Crops Research. (In press).

REGO, T. J. 1979. Nitrogen response studies of intercropped sorghum with pigeonpea. Presented atthe International Workshop on Intercropping. ICRISAT, 10-13 Jan 1979, Hyderabad, India. Proceedings in preparation.

RYAN, J. G., SARIN, R., and PEREIRA, M. 1980. Assessment of prospective soil- water- and crop-management technologies for the semi-arid tropics of peninsular India. Page 52-72 *in* Proceedings, International Workshop on Socioeconomic Constraints to Development of Semi-Arid Tropical Agriculture. ICRISAT, 19-23 Feb 1979, Hyderabad, India.

SARAF, C. S., SINGH, A., and AHLAWAT, I. P. S. 1975. Studies on intercropping of compatible crops with pigeonpea. Indian Journal of Agronomy 20(2): 127-130.

SAXENA, M. C, and YADAV, D. S. 1975. Multiple cropping with short duration pulses. Indian Journal of Genetics and Plant Breeding 35: 194-208.

SAXENA, M. C, and YADAV, D. S. 1979. Parallel cropping with short duration pigeonpea under the humid subtropical conditions of Pantnagar. Indian Journal of Agricultural Sciences 49(2): 95-99.

SEN, S., SEN GUPTA, K., SUR, S. C, and MUKHERJEE, D.

1966. A study on mixed cropping of *arhar* (*Cajanus cajan* [L] Millsp.). Indian Journal of Agronomy 11: 357-362.

SESHADRI, C. R., AIYADURAI, J. G., and SRINIVASULU, N. 1956. Groundnut mixed cropping experiment. Madras Agricultural Journal 43: 496-504.

SHARMA, D., LAXMAN SINGH, and MAHESHWARI, S. K. 1973. In M. P., soybean-arhar ensures more profit. Indian Farming 23(1): 33.

SHARMA, D., SAXENA, K. B., and GREEN, J. M. 1978. Potential of ratooning in pigeonpea. Field Crops Research 11: 165-172.

SHELDRAKE, A. R., and NARAYANAN, A. 1979. Growth, development, and nutrient uptake in pigeonpea *(Cajanus cajan).* Journal of Agricultural Science (Cambridge) 92: 513-526.

SHELKE, V. B. 1977. Studies on crop geometry in dryland intercrop systems. Ph.D. Thesis, Marathwada Agricultural University, Parbhani, Maharashtra, India.

SHETTY, S. V. R., and RAO, A. N. 1979. Weed management studies in sorghum/pigeonpea and pearl millet/groundnut intercrop systems. Presented at the International Workshop on Intercropping. ICRISAT, 10-13 Jan 1979, Hyderabad, India. Proceedings in preparation.

TARHALKAR, P. P., and RAO, N. G. P. 1978. Genotype density interaction and development of optimum sorghum-pigeonpea intercropping system. Presented at the Symposium on Intercropping of Pulses. Indian Agricultural Research Institute, 19 July 1978, New Delhi, India.

TIWARI, B. P., and BISEN, C. R. 1975. Legumes in the crop rotations, mixtures and intercropping. Indian Journal of Genetics and Plant Breeding 35: 282-290.

VEERASWAMY, R., RATHNASWAMY, R., and PALANISWAMY, G. A. 1974. Studies on mixed cropping of redgram and groundnut under irrigation. Madras Agricultural Journal 61: 801-802.

WALLIS, E. S., WHITEMAN, P. C, and AKINOLA, J. O.1975. Pigeonpea *(Cajanus cajan* [L] Millsp.) research in Australia. Pages 149-166 *in* Proceedings, International Workshop on Grain Legumes. ICRISAT, 13-16 Jan 1975, Hyderabad, India.

WALLIS, E. S., WHITEMAN, P. C, and BYTH, D. E. 1979. Pigeonpea *(Cajanus cajan* [L] Millsp.) production systems in Australia. Presented at the Regional Workshop on Tropical Grain Legumes. Department of Crop Science, 18-22 June 1979, University of the West Indies, St. Augustine, Trinidad, West Indies.

WATT, G. 1908. The commercial products of India. London: Murray.

WILLEY, R.W. 1979. Intercropping: its importance and its research needs. Field Crop Abstracts 32: 1-10, 73-85.

Pigeonpea as a Rabi Crop In India

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Abstract

Pigeonpea has traditionally been a kharif-sown (June-July) crop with an average yield of 660 kglha. The crop is generally grown mixed or intercropped with maize, millets, pulses, and oilseeds, or as a sole crop on marginal and submarginal lands. Studies since 1974-75 at Dholi, Bihar, have indicated the possibility of pigeonpea as a rabi crop with substantially high yield potential, paving the way for double and triple cropping systems with late and early cultivars, respectively, in rainfed conditions. Among the cultivars tried, Bahar, when sown in the first fortnight of September after kharif maize, has yielded 3430 kg grainlha in 209 days as against 2500 kglha in 280 days as a kharif-sown crop. Cultivars from early and medium-maturity groups have also been found promising, with yield levels of 1200 to 1700 kglha in about 130to 160days. Rabi pigeonpea has exceeded the traditional rabi crops not only in yield but also in net income and in return per rupee in vestment. This paper discusses the possible situations in which the new system could be fitted and suggests future lines of work.

Traditionally, pigeonpea (*Cajanus cajan* [L] Millsp.) is a *kharif,* or rainy-season, crop sown in June-July, with the onset of the monsoon in various agroclimatic zones of India. The crop is primarily grown mixed or intercropped with single as well as multiple crops — for example, maize, jowar, bajra, cotton, ragi, maize + urd bean, maize + urd bean + castor, maize + urd bean + sesame — in various proportions. It is grown as a sole crop on marginal, submarginal, and riverbed lands with good drainage.

Varieties included in these systems are of various maturity groups, ranging from 120 to 280 days or more, with an average productivity of only 660 kg/ha. The poor productivity and long duration of the crop have combined to reduce substantially the area sown to pigeonpea. High-yielding, short-duration varieties for different agroecological conditions and cropping systems are not yet available. The present low yields of pigeonpea may be ascribed to the traditional system of cultivation, characterized by:

- low plant population at harvest,
- high incidence of wilt and sterility mosaic,
- uncertain weather conditions during growth, and
- heavy damage by pod borers.

All these problems raise several basic questions. Can pigeonpea be cultivated as a *rabi* (postrainy-season) crop following kharif maize, paddy, or millets? Is it possible to increase the responsiveness of pigeonpea to better management practices even with currently available varieties? Can the competitiveness of the crop be increased?

To answer these questions, experiments to study the response of available varieties to time of seeding and to various other management practices, were initiated at Dholi, in northern Bihar, India, in 1974-1975. The results of the fortnightly sowings very clearly demonstrated the potential of late-sown pigeonpea (Roy Sharma 1975). These results were confirmed the following year (Roy Sharma et al. 1977). Based on these data, we undertook intensive studies on:

- the comparative performance of traditional versus rabi-sown pigeonpea,
- the competitive value of rabi pigeonpea as compared with cereals in unirrigated conditions,
- the development of profitable agronomic practices, and
- theevaluation of cultivars for various situations.

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Studies on the possibility of pigeonpea as a rabi crop were also initiated at Nayagarh in Orissa and at ICRISAT Center near Hyderabad (1975-76). In 1979, Narayanan and Sheldrake reported that pigeonpea does have potential as a rabi crop in peninsular India.

Rabi Pigeonpea Versus Traditional Rainfed Rabi Crops at Dholi

Dholi (25°39'N, 85° 40'E) with an altitude of 52.1 m above mean sea level, has a subtropical climate with dry summers. The average minimum temperature is 6.7°C (Jan) and maximum 37°C (May). Actual weather parameters for the period 1976 to 1979 are given in Table 1.

Six cropping sequences (Table 2) were included in a randomized block designto evaluate the performance of pigeonpea as a rabi crop compared with that of traditional cereals in rainfed conditions on a sandy loam calcareous soil (pH 8.5, available P_2O_5 20-23 kg/ha, organic carbon 0.395%). The agronomic operations done are presented in Appendix Table 1 and cost of cultivation, market price, etc., in Appendix Table 2.

Yield Potential

Pigeonpea cv Bahar, a long-duration cultivar maturing in 280 to 290 days as a kharif crop, yielded 3260, 4220, and 2800 kg seed/ha in the 1976,1977, and 1978 rabi seasons, respectively. These yields were substantially higher than the traditional rabi crops of wheat, barley, peas, gram, or mustard. The yield of rabi pigeonpea was also higher (average 3430 kg/ha) than that of the June-sown pigeonpea crop (2500 kg/ha sole, and 1590 kg/ha mixed with maize) at Dholi.

Further, the maize-pigeonpea sequence gave a total production of 6570 kg/ha as compared with total per hectare production from maize-barley (5830 kg), maize-wheat (5550 kg), maize-peas (5430 kg), maize-gram (4430 kg), and maize-mustard (4300 kg).

Production Efficiency

Production efficiency in terms of time (Table 2) also indicated that after 33.1 kg of maize grain/ day per ha. rabi pigeonpea (cv Bahar) produced 16.7 kg of seed yield/day per ha, as compared with 22.8,19.0,17.9, 10.7, and 8.4 kg/day per ha from barley, wheat, peas, mustard, and gram, respectively. Besides, the efficiency of rabi pigeonpea was also higher than of kharif pigeonpea as a sole crop (9 kg/day per ha). The

Table 1. Rainfall and temperature at Dholi (Musaffarpur) Bihar, India, 1976—1979.

	1976-77			1977-78			1978-79		
Month	Rainfall (mm)	Temperature Min.	(°C) Max.	Rainfall (mm)	Temperature Min.	(°C) Max.	Rainfall (mm)	Temperature Min.	(°C) Max.
Apr	3.2	21.7	32.0	75.0	21.1	35.5	21.0	18.9	35.7
May	189.2	21.9	36.8	193.0	22.1	34.0	60.0	23.4	35.3
June	181.0	25.1	37.3	81.2	25.0	34.6	157.0	25.0	34.2
July	337.2	25.0	35.7	366.5	26.0	31.9	205.0	25.2	32.2
Aug	483.0	24.5	34.0	360.3	25.9	33.1	201.5	25.5	32.5
Sept	577.0	24.7	34.7	23.8	25.3	32.6	119.0	24.1	30.5
Oct	44.0	20.3	33.9	258.5	21.2	29.4	233.8	20.7	30.5
Nov	Nil	6.5	28.5	Nil	15.3	27.3	2.5	15.0	28.5
Dec	Nil	10.0	23.5	2.1	8.8	23.8	4.0	8.8	23.9
Jan	0.3	7.6	22.4	14.0	6.7	20.9	25.8	8.8	23.0
Feb	4.1	9.8	25.7	23.3	9.0	23.9	14.5	10.1	23.4
Mar	Nil	14.9	33.5	24.3	12.2	29.0	8.0	12.0	29.0
Total	1819.0			1422.0			1052.1		

Table 2. Comparison of yields from various crop sequences at Dholi, Bihar, India.

	Grain yield (kg/ha)								Production efficiency (kg/day/ha)	
	1976-77		1977-78		1978-79		Mean yield (kg/ha)			
Crop sequence	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
Maize-Wheat	3000	2810	3750	3640	2670	800	3140	2410	33.1	19.0
Maize-Barley	3000	2590	3750	3640	2670	1830	3140	2690	33.1	22.8
Maize-Peas	3000	2650	3750	2250	2670	1980	3140	2290	33.1	17.9
Maize-Gram	3000	900	3750	2030	2670	930	3140	1290	33.1	8.4
Maize-Mustard	3000	1360	3750	1530	2670	600	3140	1160	33.1	10.1
Maize-Pigeonpea	3000	3260	3750	4220	2670	2800	3140	3430	33.1	16.7

harvest index of pigeonpea (cv Bahar) was also higher with the rabi-sown (24-30%) than with the kharif-sown crop (14-15%).

Net Income

The efficiency of a system is evaluated by its economic viability; to be adopted, the system must be practically feasible and economically profitable. Data on net income from the individual crop as well as of the sequence are given in Tables 3 and 4. In all years, rabi pigeonpea recorded a higher net income per hectare (Rs. 5741) than its counterpart traditional rabi crops: wheat (Rs. 2032), barley (Rs. 2292), peas (Rs. 3461), gram (Rs. 1627), and mustard (Rs. 2992).

The net income from the whole system showed the same pattern (Table 4). Maize-pigeonpea recorded significantly higher net income than maize-peas, maize-mustard, maize-barley, maize-wheat, and maize-gram.

In net return per rupee investment also rabi pigeonpea (Rs. 3.48) was second only to mustard (Rs. 3.63). On the basis of net return/day per ha also pigeonpea exceeded the rest of the crops (Fig. 1). Thus, rabi pigeonpea exceeded both kharif pigeonpea and all other rabi crops under rainfed conditions in terms of money and seed yield.

Evaluation of Pigeonpea as a Rabi Crop

Evaluation at Dholi

Cultivars of different maturity groups were evaluated for their performance as rabi crops at Dholi in 1977-78 and 1978-79. The planting was done at 25 x 20 cm spacing, with a basal application of 20 kg N + 50 kg P_2O_5/ha. Required protection measures were taken against pod

Table 3. Net income from various crops at Dholi, Bihar, India.

	1976-77		1977-78		1978-79		Mean		
Crop	Net income (Rs/ha)	Net return/ rupee investment (Rs)	Net income (Rs/ha)	Net return/ rupee investment (Rs/ha)	Net income (Rs/ha)	Net return/ rupee investment (Rs)	Net income (Rs/ha)	Net return/ rupee investment (Rs)	Avg crop duration (days)
Wheat	2512	2.03	3631	2.90	-48	-1.04	2031.7	1.63	127
Barley	2015	1.89	3771	3.56	1090	1.03	2292.0	2.16	118
Pea	3438	3.44	2772	2.77	4172	4.17	3460.7	3.46	128
Gram	540	0.54	2683	2.68	1659	1.66	1627.0	1.63	154
Mustard	3954	4.80	4089	4.96	934	1.13	2992.0	3.63	108
Pigeonpea	4123	2.51	6742	4.09	6358	3.85	5741.0	3.48	209

Table 4. Net income from various crop sequences at Dholi. Bihar, India.

Crop sequence	Net income (Rs/ha) 1976-77	1977-78	1978-79	Mean net income (Rs/ha)	Net income per rupee investment 1976-77	1977-78	1978-79	Mean net income per rupee investment
Maize-Wheat	4212	6246	1066	3842	1.23	1.68	0.28	1.06
Maize-Barley	3715	6386	2204	4103	1.14	1.81	0.61	1.18
Maize-Peas	5138	5387	5286	5272	1.60	1.55	1.48	1.55
Maize-Gram	2240	5298	2773	3439	0.70	1.52	0.78	1.00
Maize-Mustard	5654	6704	2048	4803	1.87	2.03	0.60	1.50
Maize-Ptgeonpea	5823	9357	7472	7552	1.52	2.27	1.77	1.85
CV(%)			13.68:	11.72			13.33	11.29
SE(±)Rs/ha	324	383	236	636	0.23	0.10	0.06	0.17
LSD (0.05)Rs/ha	963	1138	701	1889	0.27	0.33	0.18	0.51

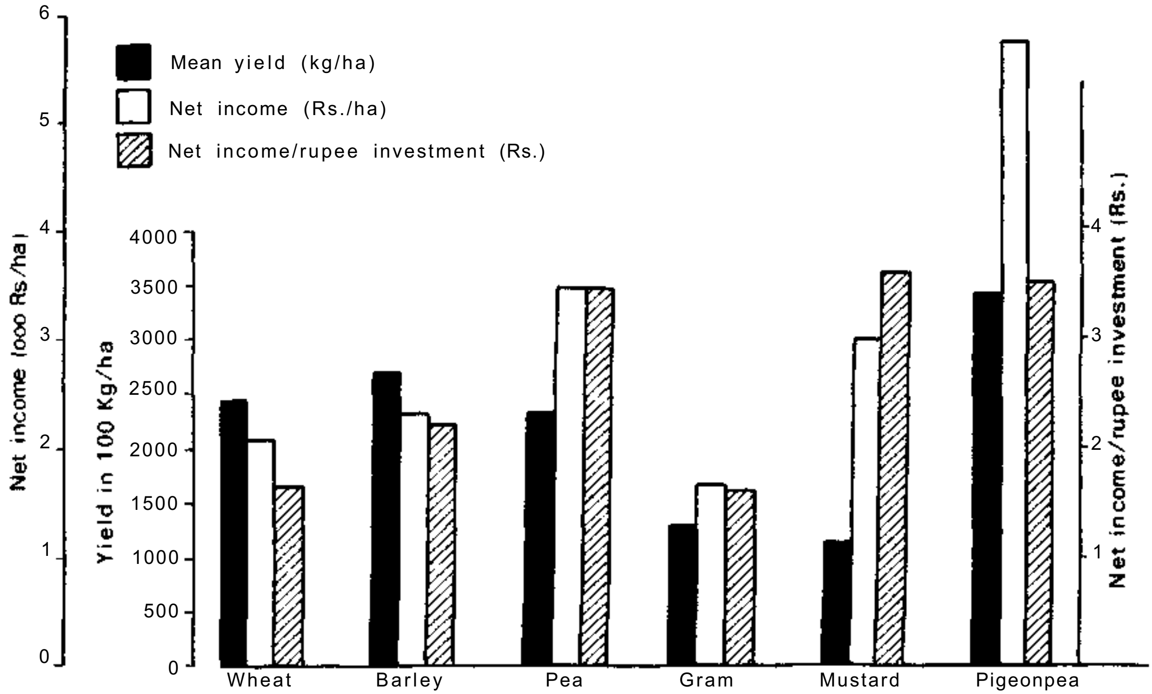

Figure 1. Yield, net income and return per rupee in vestment from pigeonpea and other rabi crops (1976-1979).

borers. Sowing was done on 8 and 10 September during 1977 and 1978, respectively. Data on yield, days to flower initiation, days to maturity, and plant height were recorded (Table 5). Cultivars were found to differ considerably in their yield potential.

Long-Duration Cultivars

Cultivars Basant and Bahar of the late group (based on knarif classification) yielded 3380 and 3430 kg/ha of grain, respectively, in 1977-78and 3090 and 3000 kg/ha, respectively, in 1978-79,

Table 5. Performance of varlatias of different maturity groups.

Cultivar	Yield (kg/ha)			Days to flower initiation	Days to maturity	Average production per day (kg/ha)	Average height (cm)
	1977-78	1978-79	Average				
Early							
UPAS-120	1330	1370	1350	63	145	9.3	102
Prabhat	1190		1190	69	160	7.4	99
Pant A-4	1570		1570	72	160	9.8	100
Pant A-1	890	1290	1090	65	146	7.5	102
TT-6	1430	1580	1500	67	153	9.8	109
Average			1340	67	153	8.8	102
Medium							
S-8	1570		1570	73	162	9.7	112
BS-1	1330	1650	1490	67	148	10.0	106
BR-183	1700	1710	1700	63	160	10.0	101
T-21	1430	1080	1250	68	150	8.3	107
Average			1500	68	155	9.7	107
Late							
Basant	3380	3090	3240	115	209	15.5	136
Bahar	3430	3000	3220	122	209	15.5	134
Average			3230	119	209	15.5	135
SE (±) (kg/ha)	135	056					
LSD (0.05)	104	165					

with a per day productivity of 15.5 kg grain/ha. Both cultivars — which normally mature in 280 to 290 days when sown in June, being photo- and thermo-sensitive — matured in only 209 days, reducing the vegetative period by 70 to80 days. These two have thus proved most promising for double-cropping systems in rainfed agriculture.

Medium-Duration Cultivars

BR-183, a cultivar recommended for Bihar state, yielded significantly higher in both the years with an average yield of 1700 kg/ha in 160 days; cvs BS-1 and S-8 had almost the same yield. Production/day per ha was almost the samefor BS-1 and BR-183.

Short-Duration Cultivars

In the early group. Pant A-4 and TT-6 with yields of 1570 and 1500 kg/ha, respectively, proved better than the rest. Data further indicated that there was stability in the yield of the crop during both years, except with Pant A-1, which produced 890 kg/ha in 1977-78 and 1290 kg/ha in 1978-79. Irrespective of the cultivars, the crop matured in about 145 to 160 days with per day productivity of 7.4 to 9.8 kg/ha. Cultivars TT-6 and Pant A-4 were thus identified as the most promising in this group. They vacatethe land by February, when crops like urd bean, mung bean, sweet potato, etc., can be planted. These cultivars have thus opened new avenues for triple-cropping systems inrainfed agriculture in agroclimatic zones similar to Dholi.

Extra-Early Cultivars

In a separate experiment, ten cultivars were evaluated in a coordinated varietal trial in breeding plots (Table 6). Sowing was done at 25-cm row spacing and 20-cm plant spacing.

Table 6. Performance of extra early cultivars at Dholi. Bihar, India, 1978-79.

Cultivar	Grain yield (kg/ha)	Days to maturity	Productivity (kg/day/ha)
ICP-1	1510	130	11.62
H 76-19	1250	126	9.92
H 76-20	1130	125	9.04
ICP-2	1100	115	9.57
H 76-53	1100	120	9.17
H 73-20	1060	128	8.28
ICP-3	1010	125	8.08
HPA-2	1000	130	7.69
ICP-4	920	112	8.21
H 76-35	900	125	7.20
LSD (0.05)	188		

Among these varieties, ICP-1, H76-19, H76-20, and ICP-2 with yields of 1510, 1250, 1130, and 1100 kg/ha, respectively, were found to be the most promising. These varieties need to be intensively tested at various locations on various soils.

Evaluation at Other Locations

Evaluation similar to that done at Dholi was done also at Kanpur. Sowing was done on 20 September, 1978. Cultivar Bahar (long duration) was found to be the best (Table 7), followed by Type 7, BDN-1, BDN-2, and C-11. These results demonstrated the feasibility of growing rabi pigeonpea in agroclimatic zones similarto Kanpur.

Similar trials have also been initiated at Varanasi and Gorakhpur in Uttar Pradesh and at Nayagarh in Orissa under the All India Coordinated Project.

Table 7. Yield of five pigeonpea cultivars at Kanpur, 1978-79.

Cultivar	Yield (kg/ha)
Bahar	2000
Type 7	1160
BDN-1	1110
BDN-2	1040
C-11	640

Effect of Sowing Dates on Yield

Studies to measure the influence of sowing dates on important cultivars of various durations have been made at Dholi, Sabour, and Kanke (Ranchi) in Bihar (1977-1979). The aim was to determine (a) optimum yields and (b) the latest sowing date compatible with profitable yields. This information is needed for developing suitable cropping patterns.

At Sabour, date of sowing significantly affected yields of late types Bahar, Basant, and 2E. Sowing on 1 September was found best for 2E; 8 September for Bahar, and 15 September for Basant. Sowing at dates later than these caused sharp decreases in yields (Fig. 2).

Similarly at Dholi also, there was a sharp decline in yield with delay in sowing beyond 10 September with variety Bahar. Sowing on 10 September yielded significantly higher (2540 kg) than on 2 October (2040 kg/ha) which in turn was significantly higher than 30 October (510 kg/ha). Early varieties too behaved in the same way (Figure 2). Varieties UPAS-120, BS-1, and TT-6 did not differ much in their yields and all the varieties yielded their maximum when sown on 10 September. In another trial at Dholi, varieties UPAS-120, BS-1, Pant A-1, and TT-6 yielded 520,490,370, and 360 kg/ha, when sown on 18 October, 1979. Similarly, planting delayed beyond September has been found to reduce total dry-matter production due to faster development rates and hence diminished yields, even with higher planting densities at Hyderabad (ICRISAT 1978). At Kanke (Ranchi), which is situated in the dryland shallow-soil zone of Chhotanagpur, Bihar, cv Bahar sown on 5 September yielded 1370 kg/ha, which was substantially higher than the June-sown crop. Even sowing on 25 September yielded 1180 kg/ha (Table 8). However, yield dropped markedly with a crop sown on 15 October.

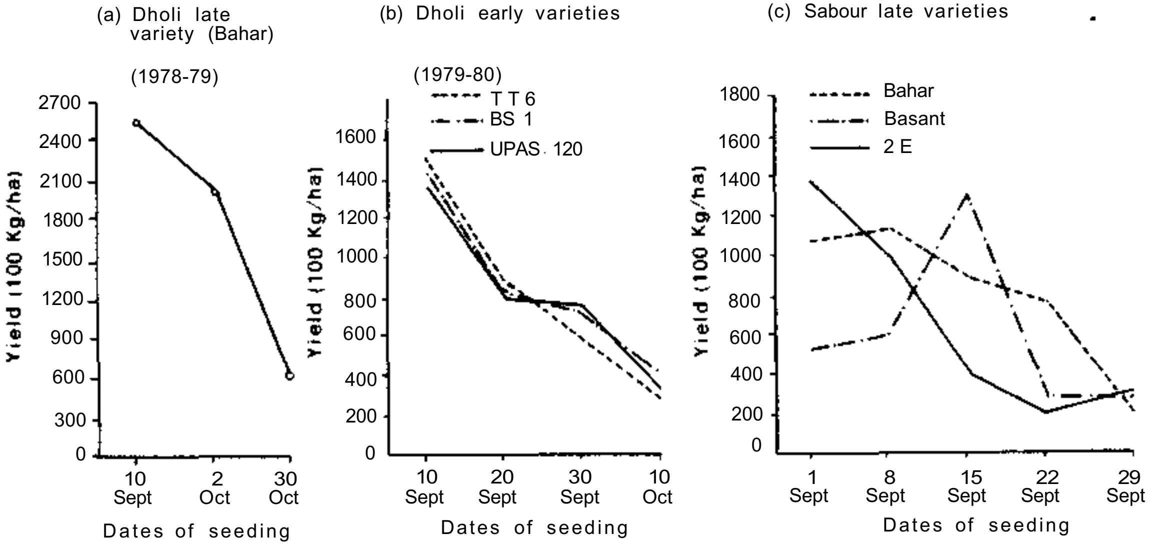

Figure 2. Performance of varieties at various dates of sowings at Dholi and Sabour.

Table 8. Effect of date of sowing on pigeonpea variety Bahar at Kanke, Ranch), India.

Sowing dates	Yield (kg/ha)
5 Sept	1370
25 Sept	1180
15 Oct	130
LSD (0.05)	53

Effect of Population Density on Yield

Population density is an important factor influencing yield. For rabi pigeonpea, row spacing of 25 cm with plants spaced at 20 cm (20 plants/m^2) has been found to be the optimum for variety Bahar (Roy Sharma et al. 1978). In the case of early varieties, sowing at 15 x 15 cm (45.5 plants/m^2) has been found to be the best (Table 9).

A rabi-sown crop responded better to higher plant population than a kharif-sown one because the growing period — and hence the vegetative growth of the plants — was less under the lower rabi temperatures.

Intercropping with Rabi Pigeonpea

The possibility of intercropping urd bean (Navin), mung bean (Amrit), and maize (M-8) in between two lines of pigeonpea sown in regular (30-cm row spacing) or paired rows (20/40 cm) has been observed to be promising. Planting of pigeonpea along with sweet potato and yam bean *(Pachyrrhizus)* in September has also been reported to be promising (Mishra and Mishra 1978). However, intercropping requires detailed study with a wide range of crops and cropping systems.

Response to Nutrients

Studies on the response of rabi pigeonpea to nutrients were initiated at Dholi in 1978-79.

Table 9. Effect of row spacing on yield of pigeonpea at Dholl, Bihar, India.

Row spacing (cm)	Yield (kg/ha)
15	990
25	780
35	710
LSD (0.05)	99

Results have indicated the positive response of the crop to 40 kg N and 60 kg P_2O_5/ha. Intensive investigation with respect to doses, forms, and modes of fertilization is in progress.

Changes in Growth and Development

Growth Rate and Leaf Fall

In general, the growth rate of plants sown in September or October has been slower, because of low temperatures during the vegetative phase as compared with the plants sown in June or July. Development rates, however, are faster, because of shorter daylengths and hence a shorter crop season. The average final height of the plants of variety Bahar (sown 10 September) in comparative performance trials was recorded as 1.07 m against 2.85 m of June-sown Bahar (Figure 3). Plants of medium and early varieties were still more dwarf. Delay in sowing was associated with shorter plants. This dwarfness may be agronomically desirable where spraying insecticides or hormones is required.

Data on the weekly leaf-fall were also gathered. Quantity of leaf-fall was appreciably higher in the June/July-sown crop (6370 kg/ha) than in the September-sown crop (2350 kg/ha). This was obviously due to difference in age of the crop plants.

Flower and Pod Formation

Time of sowing affected the duration of both flowering and podding of pigeonpea (Figure 4). Flowering began on 10 Jan 1979 in the September-sown crop, with maximum intensity coinciding with the first fortnight of February, followed by a sharp decline in the subsequent period, with almost no flowers on 14 March. In contrast, in the June-sown crop flowering began on 6 December 1978 and recorded the maximum by the third week of January, followed by a sharp decline but continued until 14March. Thus theflowering period was 64 and 99 days in the September-sown and June-sown crops, respectively.

Podding also showed a similar trend. Podding began on 24 January in the September-sown crop, with the maximum number of pods per plant in the middle of March, whereas podding began on 13 December only a week after bud initiation, in the June-sown crop and reached the maximum number of pods per plant on 14 February 1979, followed by both formation of new pods and pod drop till 21 March. Number of pods per plant declined beyond 21 March till maturity, probably due to pod drop.

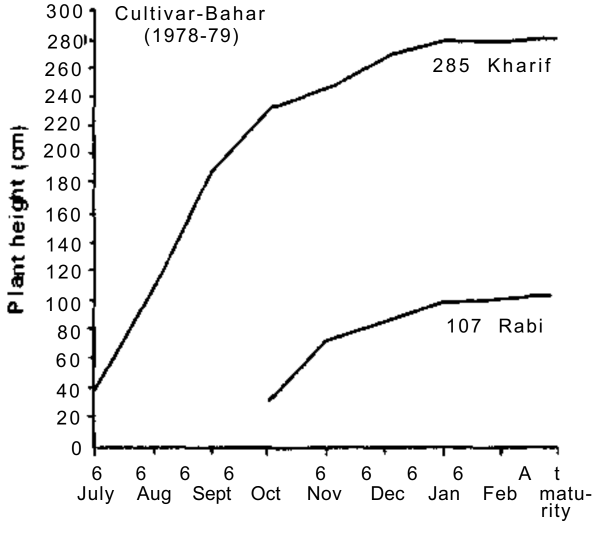

Figure 3. Growth pattern (height in cm) of June and September-sown pigeonpea at Dholi, Bihar, India.

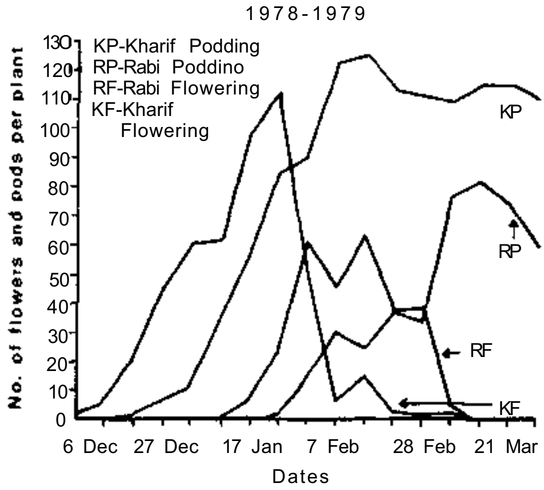

Figure 4, Pattern of flowering and podding in June and September-sown pigeonpea, var. Bahar at Dhoti, Bihar, India.

Thus, the duration of both flowering and podding was shorter in the September crop than in the June crop. This reduced period may lead to higher efficiency of insecticides applied against pod borers and also reduce the duration of sensitivity to adverse weather. This point should be examined thoroughly.

Test Weight

Test weights of grain of different cultivars sown in June and September are given in Table 10.

Irrespective of the cultivars, grains of slightly higher test weight were obtained from the kharif than the rabi crop. This is probably due to earlier initiation and/or longer period of pod formation and grain development in the June-sown crop (Figure 4) and to better exposure of pods to sunlight in the wide-row kharif crop.

Table 10. Test weight of grain of pigeonpea sown in June and September at Dholi, Bihar, India.

	1000-grain wt (g)	
Cultivar	June-sown	September-sown
Bahar	113	102
Basant	112	102
BR-183	76	76
UPAS-120	65	63
BS-1	73	71

Performance in Farmers' Plots

The performance of rabi pigeonpea has also been evaluated on 150 farmers' plots under various conditions. The highest yield recorded was 4800 kg/ha; the lowest, 2410 kg/ha; the average, 3400 kg/ha. The low yields were recorded from plots either sown later than the optimum time or with high pod borer incidence. Singh and Yadav (1979) have shown a net income of Rs. 5321/ha based on the data from farmers' plots at Dholi in 1978-79. Thus, rabi pigeonpea has been found to be practically feasible and economically viable in the Dholi region, with great potential for other agroclimatic zones as well.

Situations Where Rabi Pigeonpea May Be Possible

Against the background of the encouraging results obtained so far, the cultivation of pigeonpea may thus be tried and extended to the rabi season where winter temperatures are mild. Rabi cropping of pigeonpea could be profitable in the following situations:

1. Land vacated by kharif maize, early paddy, minor millets, paddy seedlings, or jute for fiber and after receding of floodwater in flood-prone areas of Bihar and eastern Uttar Pradesh.
2. The drier uplands in the Murshidabad districts of West Bengal.
3. The coastal region of Orissa.
4. Parts of Madhya Pradesh, particularly the districts of Raipur and Bilaspur.
5. The rice-growing areas of Karnataka and Tamil Nadu.
6. The heavy black cotton soils and the coastal areas of Andhra Pradesh.

Future Research

The feasibility of growing rabi pigeonpea has opened new avenues for increasing the production from pigeonpea, as well as the total production from pigeonpea following a well-managed sole crop of maize, paddy, or jute. Intensive research on rabi cultivation of pigeonpea and on the whole sequence should be pursued on the following lines:

1. Evaluation of the possibility and potential for growing rabi pigeonpea in all pigeonpea-growing areas of India.
2. Development and perfection of production technology suited to various agroclimatic zones of the country.
3. Development of effective and economic pest-management schedules.
4. Identification and evaluation of high-yielding varieties with faster growth rates, synchronous flowering and podding, resistance to the pest and disease complex, and improved cooking and nutritive quality of grain.

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References

ICRISAT. 1978. Pulse Physiology progress report 1977-78, Patancheru, A.P., India.

MISHRA, S. S., and MISHRA, S. 1978. Annual report, coordinated tuber research agronomy at Dholi, Bihar, 1978. Rajendra Agricultural University, Muzaffarpur, Bihar, India.

NARAYANAN, A., and SHELDRAKE, A. R. 1979. Pigeonpea (*Cajanus cajan*) as a winter crop in Peninsular India. Experimental Agriculture 15: 91-95.

ROY SHARMA, R. P. 1975. Annual report, coordinated pulse research agronomy at Dholi, Bihar, 1974-75. Rajendra Agricultural University, Muzaffarpur, Bihar, India.

ROY SHARMA, R. P. 1978. In north Bihar, new crop sequences with pulses. Indian Farming 28(6): 25.

Appendix Table 1. Operation details[a] of experiments with rabi pigeonpea at Dholi, Bihar, India, 1976-1979

Crop	Fertilizer (kg/ha) N	P_2O_5	K_2O	Spacing (cm)	Seeding rate (kg/ha)	Date of sowing 1976-77	1977-78	1978-79	Date of harvesting 1977	1978	1979
Maize	100	60	40	75 x 25	20	30 May	31 May	3 June	2 Sept	3 Sept	5 Sept
Wheat	50	30	20	20	100	18 Nov	19 Nov	18 Nov	23 Mar	29 Mar	25 Mar
Barley	30	20	20	20	100	18 Nov	5 Nov	18 Nov	14 Mar	10 Mar	22 Mar
Peas	20	45	0	30 x 10	75	1 Nov	2 Nov	18 Oct	3 Mar	15 Mar	17 Feb
Gram	20	45	0	30 x 10	75	1 Nov	2 Nov	18 Oct	29 Mar	10 Apr	24 Mar
Mustard	20	20	0	30 x 15	10	13 Oct	27 Oct	18 Oct	31 Jan	10 Feb	6 Feb
Pigeonpea	30	50	0	25 x 20	50	4 Sept	7 Sept	10 Sept	30 Mar	7 Apr	29 Mar

a. All the other recommended practices for a good crop were adopted.

Appendix Table 2. Market price of grains at harvest, by-products, and cost of cultivation of various crops.

Crop	Market price (Rs/100 kg) Grain 1976-77	1977-78	1978-79	By-product 1976-78	1978-79	Cost of cultivation (Rs/100 kg) 1976-77	1977-78	1978-79	Yield of by-products (kg/ha) 1976-77	1977-78	1978-79
Wheat	105.0	112.0	115.0	15.0	20.0	1238.80	1250.00	1250.00	5340	5 360	1430
Barley	90.0	100.0	90.0	15.0	20.0	1061.00	1060.00	1060.00	4970	7 920	2500
Peas	150.0	150.0	250.0	8.0	8.0	1004.50	1000.00	1000.00	5680	4 970	2740
Gram	150.0	150.0	250.0	12.0	12.0	1004.50	1000.00	1000.00	1640	5 360	2870
Mustard	325.0	300.0	270.0	8.0	8.0	827.30	825.00	825.00	4510	4 140	1980
Pigeonpea	160.0	175.0	270.0	7.50	7.0	1634.30	1650.00	1650.00	7250	13 280	6540
Maize	124.0	130.0	130.0	5.50[b]	5.5	1700.00	2475.00	2570.00	3000[s]	3 500	2720
				3.00[b]					500*	750	900

a. Maize stalk
b. Maize stone

ROY SHARMA, R. P., SHARMA, H. M., and THAKUR, H. C. 1977. Annual report, coordinated pulse research agronomy at Dholi, Bihar, 1976-77. Rajendra Agricultural University, Muzaffarpur, Bihar, India.

ROY SHARMA, R. P., THAKUR, H. C, and SHARMA, H. M. 1978. Potentialities of September sowing of red gram (Arhar). Presented at the National Symposium on Intercropping of Pulses. Indian Agricultural Research Institute, 1978, New Delhi, India.

SINGH, D. K., and YADAV, R. P. 1979. Report on economic analysis of various cropping systems, TCA Dholi (Muzaffarpur), Bihar, India.

Response of Short-Duration Pigeonpea to Early Planting and Phosphorus Levels in Different Cropping Systems

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Abstract

Field experiments conducted for two consecutive years at C. S. Azad University of Agriculture and Technology, Kanpur, revealed that pigeonpea cv T-21 had higher yield potential when planted in mid-April than when planted at the end of June. The yield of mung bean intercropped with April-planted pigeonpea was also increased as compared with the sole crop on an equal plant population basis. April planting resulted in taller plants with increased branching, seed size, pods, and grain yield per plant but a poor harvest index. In the new system, the vegetative growth phase of pigeonpea was prolonged but the crop matured 15 days earlier, in November. The early planted crop was more responsive to phosphate fertilization. The subsequent wheat crop gave a higher yield and needed less fertilizer phosphorus. A marked increase in net income of Rs. 279Slha was realized by adopting the cropping system based on April-planted pigeonpea. Implications for future research to improve the system have been suggested.

Short-duration varieties of pigeonpea are harvested much earlierthan the onset of frost; they can also be fitted into the double-cropping system with wheat in areas of assured irrigation. Planting of pigeonpea cv T-21 before the onset of the monsoon in the first fortnight of June has recorded maximum yield in a multi location trial conducted in the central *and* western parts of Uttar Pradesh (Panwar and Misra 1973; Rathi and Tripathi 1978); at Pantnagar (Saxena 1973); Ludhiana (Kaul and Sekhon 1977); and Hissar (Faroda and Singh 1978). Planting dates earlier than June have rarely been tried. The earliest reports are available from West Bengal (Anonymous 1948-53). It has been indicated that early planting— 10 May— in 1951 and 1952 recorded much higher yields than the later dates of planting in May and June. Similarly Saxena and Yadav (1975) have also reported higher yields with the earliest planting date (20 May 1970) of cv T-21 at Pantnagar. Delay in planting not only reduced the yield of pigeonpea but also drastically reduced the yield of the subsequent wheat crop (Kaul and Sekhon 1977).

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Intercropping of black gram (urd bean) and green gram (mung bean) with short-duration pigeonpea has been found to be very profitable, with no adverse effect on the main crop in the experiments conducted throughout north India (Panwar 1979a). However, early planting in May or the first fortnight of June will be deleterious to these short-duration intercrops, as the flowering and fruiting will coincide with the peak period of rainfall in August. The planting of pigeonpea + urd/mung by the end of June or in July, may often give a good yield of the intercrop, but the yield of pigeonpea is bound to be reduced due to delay in sowing.

Summer mung after the harvest of wheat has now become quite popular in the northern plains. It gives higher yields than its rainy-season crop, because it involves little risk. Any *kharif* (rainy-season) crop can follow the summer mung in fields vacated in the second fortnight of June.

An all-India review on fertilizer use in kharif pulses (Panwar 1980a) has shown that the responses to phosphatic fertilization of pigeonpea, mung, and urd have been generally positive and in some cases highly significant, on soils testing low in available phosphorus. Almost no information is available regarding the phosphate requirements of different cropping systems involving three pulses (pigeonpea, urd, and mung) followed by wheat, in one calendar year. The present investigation was carried out to study the phosphate responses, production potential, and economics of two cropping systems differing mainly in the planting dates of pigeonpea cv T-21.

Experimental Methods

A field experiment was initiated in the summer (*jaid*) season of 1977 at the Students Instructional Farm of C. S. Azad University of Agriculture and Technology, Kanpur. The soil of the experimental plot was sandy loam in texture and medium low in fertility. Two parallel multiple-cropping sequences comprising three pulse crops followed by wheat were tested at four levels of phosphorus to each crop in a split-plot design with four replications (Table 1).

In the first cropping pattern, pigeonpea + mung was planted in mid-April, keeping pigeonpea rows at 90 cm, intercropped with three rows of mung. After harvesting mung in the fourth week of June, interplanting of urd was done in two rows between pigeonpea rows on 30 June. Intrarow spacing of pigeonpea was maintained at 30 cm. Urd bean took 90 days to mature. Flower initiation in pigeonpea was recorded in the second week of September and the crop matured in the second week of November. A wheat crop was then planted in the fourth week of November.

In the second cropping pattern, mung was planted in mid-April, with a 30 cm row spacing. After harvesting of mung, the sowing of pigeonpea + urd was done on 30 June, with pigeonpea rows 60 cm apart intercropped with one row of urd. The flower initiation in pigeonpea took place by the end of September and the crop matured in the first week of December. Wheat sowing took place by the middle of December. The experiment continued for two consecutive years (1977-78 and 1978-79).

Phosphorus levels in the form of single superphosphate were given to each component crop in the rotation. Nitrogen through urea at 10 kg N/ha to each pulse crop and 120 kg N/ha to wheat was given uniformly.

Four irrigations were given in the summer, two in the rainy season, and six in the postrainy season, including those required for land preparation.

Table 1. Response to varying levels of phosphorus of thraa pulse crops.

Main-plot treatments (pulse crops)	Subplot treatments (wheat crop)
Factor A. Cropping pattern	Factor C. Phosphorus levels
1. Mung bean T-44 - (Pigeonpea T-21 + urd bean T-9) - wheat	0, 20,40, and 60 kg P_2O_5/ha
2. Pigeonpea T-21 + (Mung T-44-urd T-9) - wheat	
Factor B. Phosphorus levels to each crop 0, 20,40 and 60 kg P_2O_5/ha	

Results and Discussion

Growth and Yield of Pigeonpea Planted in April

The data presented in Tables 2 and 3 clearly indicate the effect of date of planting and phosphorus levels on the growth and yield of pigeonpea.

Significant effect of date of planting was recorded on all plant characters. April planting resulted in very tall plants (291 cm), 124 cm taller than the June planted crop; more number of branches (74.4%) and pods (65.5%); bolder and heavier seeds (12.9%); and more grain yield (223%) per plant over the June-end planting. The per hectare yield of dry sticks was 182% higher, and the yield of grain (2598 kg/ha) was about 50% higher than that of the June-end planting (1736 kg/ha).

These results may be discussed in the light of the longer vegetative phase and taller plants with more branching in the April-planted crop. The large amount of photosynthates, when converted in the reproductive phase, brought

Table 2. Growth attributes and yield of dry sticks of pigeonpaa as affected by date of planting and phosphate application.

Date of Planting	P_2O_5 (kg/ha)	Plant height (cm) 1977	Plant height (cm) 1978	Plant height (cm) Mean	Primary branches (no.) 1977	Primary branches (no.) 1978	Primary branches (no.) Mean	Yield of dry sticks (kg/ha) 1977	Yield of dry sticks (kg/ha) 1978	Yield of dry sticks (kg/ha) Mean
30 June	0	142	142	142	7.7	11.5	9.6	4 600	4 500	4500
	20	157	152	154	10.7	13.2	11.9	5 500	6 000	5 700
	40	169	184	176	13.0	14.3	13.6	5 900	6 200	6 000
	60	172	187	179	14.3	15.4	14.8	5 800	6 600	6 200
	Mean	160	167	163	11.4	13.6	12.5	5 500	5 900	5 700
15 April	0	267	283	275	17.8	19.5	18.6	12 400	16 200	14 300
	20	290	290	290	22.3	21.2	21.7	15 000	16 900	15 900
	40	294	296	295	23.6	22.3	22.9	16 800	17 200	17 000
	60	301	309	305	24.8	23.0	23.9	17 100	17 700	17 400
	Mean	288	295	291	22.1	21.5	21.8	15 300	17 000	16 100
Mean	0	204	213	208	12.8	15.5	14.1	8 500	10 400	9 400
	20	224	221	222	16.5	17.2	16.8	10 300	11400	10 800
	40	235	240	237	18.3	18.3	18.3	11300	11700	11500
	60	236	248	242	19.6	19.2	19.4	11400	12 200	11800
LSD (5%)	S	5	2		0.8	0.2		600	50	
	P	7	3		1.2	0.3		800	70	
	SP	NS	4		NS	NS		1 200	90	

about a marked increase in the number of pods, size of grain, and grain yield per plant. But the per hectare yields were not increased to the extent of the increases obtained in yield per plant. This can be attributed, first, to the lower number of plants per hectare in the April-planted crop (about 37 000 plants/ha) than in the June crop (83 000 plants/ha). It is necessary to maintain this difference in plant population because of the different growth patterns under the two sowing dates. Secondly, the reproductive phase in the two systems is almost the same. In the April-planted crop the proportion of photosynthates converted into grain is lower than in the June-planted crop. This is very well reflected by the poor harvest index of the April-planted crop.

Response of Pigeon pea to Phosphorus

Phosphate application resulted in significant increase in all the characters studied. Phosphate fertilization at 60 kg P_2O_5/ha increased the plant height (34 cm), primary branches (5.3), pods per plant (134), test weight of grain (14.7 g/1000 grains), and grain yield per plant (44.3 g) and per hectare (1211 kg) over the control.

The interaction of phosphorus x date of sowing was significant. The grain yield per plant and per hectare increased linearly up to the highest dose when the crop was planted in April. The response was significant up to 40 kg P_2O_5/ha in the June-planted pigeonpea. However, the economic optimum dose for the latter was as high as 65 kg P20s/ha.

The fertilizer responses presented in Table 4 indicate that the yield of April-planted pigeonpea can be enhanced further to more than 3343 kg/ha by applying doses higher than 60 kg P_2O_5/ha.

Mung Yields

The grain yield data (Table 4) on mung revealed

Table 3. Yield attributes, grain yield, and harvest index of pigaonpaa as affactad by data of planting and phosphate application.

Date of Planting	P_2O_5 (kg/ha)	Pods/plant (no.)			1000-grain wt (g)			Grain yield (g/plant)			Grain yield (kg/ha)			Harvest index (%)
		1977	1978	Mean	1977	1978	Mean	1977	1978	Mean	1977	1978	Mean	
30 June	0	155	171	163	64.0	59.2	61.6	18.9	22.4	20.6	1197	1200	1198	21.0
	20	217	284	250	68.8	65.0	66.9	29.2	34.4	31.8	1587	1607	1597	21.9
	40	275	296	285	73.2	73.2	73.2	36.8	41.6	39.2	1923	2151	2037	25.3
	60	294	324	309	75.5	76.0	75.7	39.3	42.7	41.3	1973	2247	2110	25.4
	Mean	235	269	252	70.0	68.3	69.1	31.2	35.3	33.2	1670	1802	1736	23.3
15 April	0	258	231	244	71.5	71.0	71.2	77.7	78.6	78.1	1844	1817	1830	11.3
	20	365	391	378	76.0	74.6	75.3	99.1	106.4	102.7	2358	2306	2332	12.8
	40	467	483	475	79.8	78.3	79.0	113.6	121.4	117.5	2800	2970	2885	14.5
	60	537	594	565	83.0	90.0	86.5	124.3	135.4	129.8	3160	3526	3343	16.1
	Mean	407	425	416	77.6	78.5	78.0	103.8	110.4	107.1	2541	2655	2598	13.9
Mean	0	206	201	203	67.7	65.1	66.4	48.3	50.5	49.4	1521	1509	1515	13.9
	20	291	337	314	72.4	69.8	71.1	64.2	70.4	67.3	1973	1956	1964	15.4
	40	371	389	380	76.5	75.7	76.1	75.2	81.5	78.3	2361	2561	2461	17.6
	60	415	459	437	79.2	83.0	81.1	82.4	89.0	85.7	2566	2886	2726	18.8
LSD (5%)	S	16	7		0.6	0.7		9.3	1.3		126	54		
	P	22	9		0.9	1.0		13.2	1.9		179	76		
	SP	31	13		NS	1.4		NS	2.7		253	108		

somewhat peculiar results. When the same plant population was maintained as intercrop in pigeonpea, mung yield was 137 kg/ha higher than sole-crop mung. This is probably due to a more favorable microclimate and beneficial root interaction in the intercropping system. Pigeonpea plants protect the intercrop from desiccating winds and keep the mung upright; also probably the side rows get the advantage of the phosphorus applied to pigeonpea rows.

Mung responds to phosphate application but the incremental responses are of a lower magnitude than in other crops, particularly at the 20 and 40 kg P_2O_5/ha levels. The sole crop is more responsive to graded levels of the fertilizer. The fertilizer application has been found to be economical up to the higher doses of 79.7 and 88.4 kg/ha for the sole and intercrop respectively. Economic responses to higher doses of phosphorus (100 kg P_2O_5/ha) have been reported by Moolani and Jana (1965) on acidic lateritic soils and by Maheshwari (1974) on soils with low phosphorus status.

Urd Yields

The interplanting of urd T-9, after the harvest of mung between rows of 75-day-old pigeonpea was not successful because of shading by pigeonpea. In contrast to this, the intercropping of urd between June-planted pigeonpea was very successful, recording a mean yield of 1242 kg/ha.

Phosphorus application had a marked effect up to 40 kg P_2O_5/ha for the intercrop; economic optimum dose, however, was 60 kg P20s/ha. For the interplanted crop, a low dose of 12.5 kg P_2O_5/ha was economic. Positive responses to the application of 60 kg P_2O_5*lha* have already been reported from experiments at research farms and cultivators' fields in Uttar Pradesh (Panwar 1979b).

Table 4. Response of different crops to applied fertilizer phosphorus in two cropping systems (pooled over two seasons).

Cropping system	Crop	Model	Pooled grain yield (kg/ha) at different levels of P_2O_5 (kg/ha) 0	20	40	60	Mean	Optimum dose (P_2O_5 kg/ha)
1 Pigeonpea/Mung + Urd - Wheat								
	Pigeonpea	$Y = 11.78 + 0.28\ P - 0.0002\ P^2$	1198	1597 (20.0)[a]	2037 (22.0)	2110 (3.65)	1736	65.0
	Mung	$Y = 19.06 + 0.11\ P - 0.0005\ P^2$	1005	1199 (9.7)	1343 (7.2)	1452 (5.4)	1250	79.7
	Urd	$Y = 8.87 + 0.18\ P - 0.0014 P^2$	887	1197 (15.5)	1399 (10.1)	1485 (4.3)	1242	60.0
	Wheat	$Y = 46.44 + 0.32\ P - 0.002\ P^2$	4656	5210 (28.0)	5620 (20.5)	5862 (12.1)	5337	71.4
2 Mung - Pigeonpea/Urd - Wheat								
	Pigeonpea	$Y = 18.35 + 0.2543\ P$	1830	2332 (25.1)	2885 (27.6)	3343 (22.9)	2598	
	Mung	$Y = 12.21 + 0.07\ P - 0.0005\ P^2$	1222	1344 (6.1)	1454 (5.5)	1525 (3.5)	1387	88.4
	Urd	$Y = 0.46 + 0.02\ P - 0.0002\ P^2$	46	80 (1.7)	98 (0.9)	102 (0.2)	82	12.5
	Wheat	$Y = 61.69 + 0.31\ P - 0.0027 P^2$	6163	6701 (26.9)	6958 (12.8)	7038 (5.2)	6721	50.4

a. Figures in parentheses are incremental responses in kg grain/kg of applied P_2O_5 at various levels.

Wheat Following April-Planted Pigeonpea

Wheat planting could be done about 15 to 20 days earlier after harvesting an April-planted pigeonpea crop. Because of the early harvesting and greater soil enrichment by organic residues in the form of huge leaf shedding and root growth of the pigeonpea, the subsequent wheat crop had an excellent performance, with a mean yield of 6721 kg/ha. In contrast to this, the wheat crop following June-planted pigeonpea could be sown late, only in the middle of December, and recorded a mean grain yield of 5337 kg/ha.

The response of wheat to phosphorus at a low level of 20 kg P_2O_5 was almost similar in thetwo cropping systems. However, at higher levels, the late-sown crop exhibited a greater response. The optimum dose of phosphorus for this crop was as high as 71.4 kg P_2O_5/ha. The wheat sown after April-planted pigeonpea had less response to higher doses, the economic optimum dose being only 50.4 kg P_2O_5/ha (Table 4).

The data on grain yield of wheat (Table 5) reveal that the residual effect of phosphorus applied to previous pulse crops was more in wheat sown after April-planted pigeonpea. Perhaps the deep and more extensive root system and the huge leaf shedding are responsible for the recycling and greater mineralization of the soil phosphorus. The timely sown crop made a more efficient use of this residual content. On the other hand, the availability of phosphorus goes down as the sowings of wheat crop are delayed. As a result of this, the effect of residual phosphorus is less and the crop responds more to higher levels of applied phosphorus.

The maximum yields (6184 kg/ha) of wheat after June-planted pigeonpea were obtained where 120 kg P_2O_5 was applied to the pulse and 60 kg P_2O_5 to the wheat crop. With wheat after April-planted pigeonpea, the maximum yield (7314 kg/ha) was recorded when 180 kg P_2O_5

Table 5. Grain yield of wheat as affected by residual phosphorus and direct application under two cropping systems (pooled over two seasons).

Cropping System	P2O5 to knar if pulse (kg/ha)	Grain yield (kg/ha) of wheat at kg P_2O_5/ha of 0	20	40	60	Mean
1	P_0	4153	4747	5202	5512	4903
	P_{60}	4564	5169	5699	6041	5368
	P_{120}	4861	5463	5830	6184	5585
	P_{180}	5046	5463	5750	5714	5493
	Mean	4656	5210	5620	5862	5337
2	P_0	5482	6023	6509	6737	6188
	P_{60}	6061	6705	6924	7064	6688
	P_{120}	6456	6922	7084	7188	6912
	P_{180}	6653	7157	7314	7264	7097
	Mean	6163	6701	6958	7063	6721
Mean	P_0	4817	5385	5855	6124	5545
	P_{60}	5312	5937	6311	6552	6028
	P_{120}	5658	6192	6457	6686	6248
	P_{180}	5849	6310	6532	6489	6295
	Mean	5409	5955	6289	6462	6029

was given to the pulse and 40 kg P_2O_5 to the wheat crop. The responses diminished when the maximum dose (180 kg) to pigeonpea was followed by the maximum dose (60 kg P_2O_5) to the wheat crop.

The Economics of April-Planted Pigeonpea

The profits from the cropping system involving April-planted pigeonpea are more than from the other cropping system. The cost of cultivation in the first instance was Rs. 297/ha higher than in the second. The new cropping system resulted in a net income of Rs. 18 656/ha as against Rs. 15 861/ha from June-planted pigeonpea. In spite of thefailure of interplanting of black gram inthe new system, this increase of Rs. 2795/ha is remarkable (Table 6).

The gross income from wheat was much higher than that from pigeonpea in the conventional system, whereas in the new cropping system pigeonpea has proved to be equally profitable. The gross profits from April-planted pigeonpea are even higher than those obtained from wheat when 60 kg P_2O_5/ha was applied to each crop.

The incremental responses in net profit per kg of applied fertilizer P_2O_5 and per rupee invested on fertilizer are higher in the new system, particularly at the 20 and 40 kg P_2O_5 levels. However, at 60 kg P_2O_5 level the reverse is true, because of the major role of April-planted pigeonpea, which responded linearly upto 60 kg P_2O_5/ha.

Implications for Future Research

Of the four crops tested, urd has not been successful in the new cropping system. Alternative cropsthat can grow better undershade may be tested. In this system the harvest index of pigeonpea is to be improved. Higher doses of phosphorus to pigeonpea with total elimination of starter N doseto all pulses may perhaps be of some use in this direction. The flowering and maturity in the April-planted pigeonpea is less synchronous. At 90 cm x 30 cm spacing the

Table 6. Economics of phosphate fertilization In different cropping systems pooled over two seasons.

Cropping system	Crop	Kg P_2O_5/ha to each crop Control	20	40	60	Mean
				Gross income (Rs/ha)		
1	Pigeonpea	4 044	5 361	6711	6 950	5 766
	Mung	3 762	4 496	5 040	5 642	4 735
	Urd	2 816	3 766	4412	4 680	3918
	Wheat	6 900	7 632	8 265	8 647	7 861
	Total	17 522	21 255	24 428	25 919	22 281
2	Pigeonpea	6 920	8 586	10 355	11769	9 408
	Mung	4 622	5 074	5 474	5 737	5 227
	Urd	148	250	309	321	257
	Wheat	9 063	9 916	10217	10 369	9 891
	Total	20 753	23 826	26 355	28 196	24 783
				Cost of cultivation (Rs/ha)		
1		5 850	6 230	6610	6 990	6 420
2		5 557	5 937	6 317	6 697	6 127
				Net income (Rs/ha)		
1		11672	15 025	17818	18 929	15861
2		15 196	17 889	20 038	21 499	18 656
				Response[a]		
1		(Rs/kg/ha)	167.25	139.65	55.55	
		(Rs/Re/ha)	(8.82)	(7.35)	(2.92)	
2		(Rs/kg/ha)	134.65	107.45	73.05	
		(Rs/Re/ha)	(7.09)	(5.66)	(3.84)	

a. Incremental responses in net profit per kg of applied fertilizer (P_2O_5) and per rupee invested on fertilizer.

pods are concentrated on the top branches. Preliminary investigations at Kanpur have indicated thattopping of April-planted pigeonpea in the first fortnight of August increased the number of branches and pods and resulted in synchronous maturity and higher yields (Panwar 1980b). Plant population and the extent and time of topping studies are yet to be completed.

The new cropping system is now being adopted in irrigated areas of western and central Uttar Pradesh; the higher and assured yields of pigeonpea, mung, and wheat with less fertilizer nitrogen and phosphorus have tempted the farmers to try it out. A heavy tonnage of dry sticks of pigeonpea to meet the present fuel shortage and buildup of soil fertility are two of the very strong plus points in favor of this system. Research work is needed, however, to quantify the nitrogen economy and fertility restoration under this system.

References

ANONYMOUS. 1948-53. National index of agricultural field experiments, West Bengal 14(1): 146-148.

FARODA, A. S., and SINGH, R. C. 1979. Agronomy in pigeonpea research in Haryana. Presented at the Pigeonpea Scientists Meeting, Rajendra Agricultural University, Pusa, Bihar, India.

KAUL, J. N., and SEKHON, H. S. 1977. Research on kharif pulses, annual reports 1974-77. Punjab Agricultural University, Ludhiana, India.

MAHESHWARI, S. K. 1974. Response of green gram (*Phaseolus aureus)* to inoculum and levels of N and P with their economics. JNKVV Research Journal 8(2): 157-58.

MOOLANI, M. K., and JANA, M. K. 1965. Response of green gram *(Phaseolus aureus* L) to fertilizers in laterite soil. Indian Journal of Agronomy 10(1): 43-44.

PANWAR, K. S., and MISRA, A. S. 1973. Recommendation for the agronomy of kharif pulses. NinthAnnual Workshop on Kharif Pulses. IARI, June 1973, New Delhi, India.

PANWAR, K. S. 1979a. A critical view of pigeonpea intercropping research in India. Presented at the Summer Institute on Pulse Production Technology. Haryana Agricultural University, June-July 1979. Hissar, India.

PANWAR, K. S. 1979b. Response of pulses to application of fertilizers in U.P. soils. FAI(NR)-HAU Group Discussion. Haryana Agricultural University, October 1979, Hissar, Haryana, India.

PANWAR, K. S. 1980a. Review of efficient fertilizer use in kharif pulses and oilseeds. Presented at the FAI-BHU Seminar. March 1980, Varanasi, India.

PANWAR, K. S. 1980b. Pulse agronomy report of C. S. Azad University, Kanpur. Presented at the All India Coordinated Kharif Pulses Workshop, Kanpur, India.

RATHI, K. S., and TRIPATHI, H. N. 1978. Studies on time of sowing, row spacing and phosphate fertilization of early maturing *arhar* variety T-21 in central Uttar Pradesh. Indian Journal of Agronomy 23(3): 233-237.

SAXENA, M. C, and YADAV, D. S. 1975. Some agronomic considerations of pigeonpea and chickpea. Pages 31-62 *in* Proceedings, International Workshop on Grain Legumes. ICRISAT, 13-16 Jan 1975, Hyderabad, India.

Extending Pigeonpea Cultivation to Nontraditional Areas in India

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Abstract

Traditionally, pigeonpea cultivars grown in India have been long-duration types; however, development of early and extra early types has opened up new areas for pigeonpea cultivation. These potential areas include frost-prone tracts in northern India, the new canal command areas of the northwestern states, rice fallows, and flood-prone areas after the receding offloodwater. Postrainy-season pigeonpea has also been shown to give high yields and net income per hectare. This paper outlines appropriate agronomic practices and lists cultivars suitable for growing in nontraditional areas.

Pigeonpea (*Cajanus cajan* [L.] Millsp.), known by the common names red gram, tur, arhar, and others, is the second most important grain legume of India, after chickpea. Pigeonpea — grown mainly in the states of Uttar Pradesh, Madhya Pradesh, Maharashtra, Karnataka, Bihar, Gujarat, Tamil Nadu, and Andhra Pradesh — occupies about 11% of the total area under grain legumes in India and contributes about 17% to their total production (Table 1). It is grown in a wide variety of soils, ranging from sandy to heavy clay soils and pH 5.0 to 8.0. However, well-drained, deep loam soils, free from excessive soluble salts and near-neutral in pH, are most suitable (Pathak 1970). Pigeonpea is a tropical or subtropical plant and cannot tolerate even light frost during any stage of its growth. Waterlogging is also detrimental to its growth.

Traditionally, long-duration varieties of pigeonpea are cultivated in India; however, with the release of early (150-160 days) and extra early (120-130 days) varieties, the possibilities of extending pigeonpea cultivation to nontraditional areas have increased.

Table 1. Area and production of pigeonpea in different states of India, 1977-78.

States	Area (000 ha)	Production (000 tonnes)
Andhra Pradesh	198.60	29.90
Assam	5.61	3.93
Bihar	105.00	65.00
Gujarat	111.40	44.20
Haryana	2.12	1.71
Karnataka	303.88	181.88
Kerala	3.02	0.75
Madhya Pradesh	503.10	363.20
Maharashtra	660.30	344.30
Orissa	61.50	25.89
Punjab	3.80	1.80
Rajasthan	33.51	10.39
Tamil Nadu	101.35	44.08
Uttar Pradesh	504.56	749.28
West Bengal	22.80	20.50
Other States	2.45	1.10
Total	2623.00	1887.91

Source: Agricultural situation in India (1979).

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New Areas for Pigeonpea Cultivation

Frost-Affected Areas

Becausefrost readily kills pigeonpea, it is grown mostly in frost-free areas and seasons. Frost generally occurs in December and January in areas of western U.P., Delhi, Haryana, western Rajasthan, Punjab, Himachal Pradesh, and Jammu and Kashmir. However, the early and extra early varieties, when sown from mid-June to the first week of July, can be harvested by the end of November or early December and thus escape frost. The following crop of wheat, or any other winter crop, can be sown after the pigeonpea harvest.

New Canal Command Areas

Canal irrigation facilities are increasing rapidly. The large areas under the Rajasthan canal, Jawaharlal Nehru canal, and Indira Gandhi canal in Rajasthan and Haryana and similar areas in other states can be brought under pigeonpea cultivation. At present this area is put under pearl millet, clusterbean, or sorghum. The pigeonpea-wheat rotation is more profitable than maize-wheat or pearl millet-wheat (Jeswani 1979); where irrigation is available, the early and extra early varieties of pigeonpea can be used in the pigeonpea-wheat rotation (Pannu and Sawhney 1975).

Rice Fallows

In rice-growing areas where winters are mild, with no frost, a second crop of rice is taken where irrigation is available. Where irrigation is not available, grain legumes such as mung bean, urd bean, and cowpea are grown in rice fallows on residual moisture. Pigeonpea could be a suitable crop in such situations, because it has higher yield potential than many other pulses.

Lenka and Satpathy (1976) have advocated sowing of pigeonpea in rice fallows in Orissa. Studies made at the Central Rice Research Institute, Cuttack, showed that in well-drained light-textured uplands, a number of winter crops — such as mung bean, groundnut, chickpea, cotton, wheat, linseed, and potato — could be successfully grown after the harvest of an early rainy-season (July-October) rice crop in eastern India, where irrigation facilities exist (Mahapatra et al. 1971). Similar results have been reported by Mandal and Singh (1971) from Kerala. Under these situations there is great scope for extending pigeonpea cultivation.

Winter Crop

In India, pigeonpea is normally sown at the beginning of the rainy season (June-July). The medium-duration varieties take about 5 to 7 months to mature and long-duration varieties more than 7 months, maturing in February and March. Thus only one crop of pigeonpea can be taken in a year. Studies conducted in Bihar (Roy Sharma et al. 1979) and at ICRISAT (1977) have shown that a winter crop of pigeonpea can be grown successfully as a nonirrigated crop where rainfall is sufficient and frost does not occur. An early-maturing rainy-season crop like maize can be taken before pigeonpea. The winter-planted pigeonpea crop has a shorter maturity period, a higher harvest index, and a lower incidence of diseases and insect pests, and it gives yields equal to or higher than the June-July planted crop (Roy Sharma et al. 1979).

Roy Sharma et al. (1978) tried wheat, barley, peas, chickpea, mustard, and pigeonpea after a rainy-season crop of maize in Bihar. Maize-pigeonpea rotation gave maximum yield and net income per hectare.

In areas where winter is very mild and frost does not occur, a winter crop of pigeonpea can be taken after rainy-season crops like maize, early paddy, or short-duration pulses, or after receding of floodwater in flood-prone areas.

Intercropping

A large area in south India is under plantation crops such as coconut, banana, tapioca, etc. Natarajan and Vittal (1975) and Gopalakrishnan (1975) have recommended intercropping of pulses, including short-duration pigeonpea in coconut, banana, tapioca, and sugarcane. They have also recommended sowing of pigeonpea and other pulses on the bunds of rice fields.

Agronomic Management Practices for Early Varieties

Frost-Affected and Canal Command Areas of North India

Suitable Cultivars

A wide choice of pigeonpea varieties is now available for these areas, which are mainly double-cropping areas. Wheat is the main winter crop and the pigeonpea crop should vacate the field by the end of November or early December. The early and extra early varieties (maturing in 120 to 160 days) such as Prabhat, UPAS-120, Pant A-1, Pant A-3, T-21 etc. are well suited for the northwestern arid to semi-arid regions of Rajasthan, Haryana, parts of Punjab, western Uttar Pradesh, and Delhi. These varieties have been tested on research farms and on farmers' fields (Tables 2-6). The varieties UPAS-120, T-21, Prabhat, Pant A-1, and TT-6 performed better than others at various locations in Haryana. However, variety P-4785 gave maximum yield under Delhi conditions. The agroclimatic conditons of western Rajasthan (Rajasthan canal area) and Punjab are similar to those in Haryana, and the above varieties can successfully be grown in these areas.

Sowing Time

For western Uttar Pradesh, Haryana, Punjab, Delhi, and western Rajasthan, sowing from the second week of June to the end of June has been found optimum for getting maximum

Table 2. Performance of early-maturing pigeonpea cultivars at various locations in Haryana.

	Grain yield at different locations (kg/ha)					
	1975		1976		1977	
Cultivar	Hissar	Gurgaon	Hissar	Ambala	Hissar	Ambala
H 73-20	1633	1104	3071	1225	1421	784
H 72-44	1240	1070	2223	1095	1511	500
Prabhat	888	649	1910	1175	1242	627
UPAS-120	1455	988	2502	1300	1361	1080

Source: Anonymous (1979).

Table 3. Performance of early-maturing pigeonpea cultivars at Hissar, Haryana.

	Grain yield (kg/ha)					
Cultivar	1973	1974	1975	1976	1977	Average
Prabhat	799	1872	1342	2262	1592	1573
UPAS-120	835	2147	1395	2365	1919	1732
T-21		1856	1459	2214	1748	1819
BS-1			1225			1225
Pant A-2			1217			1217
Pant A-1				2122	1578	1850
TT-6					1550	1550
LSD (5%)	NS	153	101	NS	130	

Source: Anonymous (1979).

Table 4. Performance of early-maturing pigeonpea cultivars on farmers' fields In canal command area, Mohendergarh District, Haryana.

Cultivar	Grain yield (kg/ha)				
	Tihara	Shahpur	Bawal	Karnawas	Average
UPAS-120	1243	1030	1320	1354	1237
TT-6	1600	1540	1630	1440	1557
Pant A-1	1168	1254	1040	1070	1133
H. 73-20	1460	1148	1330	1240	1294
Prabhat	846	840	940	830	864

Source: Anonymous (1978).

Table 5. Performance of short-duration cultivars of pigeonpea on farmers' fields in Haryana.

Village	District	Year	Grain yield (kg/ha)		
			Prabhat	UPAS-120	T-21
Mulakpur	Ambala	1974	1200	1310	1640
Hayatpur	Gurgaon	1974	1640	1220	1830
Bamla	Bhiwani	1978	1250	1310	
Sonepat	Sonepat	1978	1240	2220	
Parbhuwala	Hissar	1978	1200	1650	

Source: Anonymous (1979).

Table 6. Performance of early-maturing pigeonpea cultivars under Delhi conditions.

Cultivar	Grain yield (kg/ha)		
	1970	1971	Mean
T-21	1920	1760	1840
AS-3	1870	1710	1790
AS-5	2130	1900	2010
P-4785	2350	2160	2260
LSD (5%)	60	60	40

Source: Singh et al. (1976).

yield of early and extra early pigeonpea varieties (Panwar and Misra 1975; Faroda and Singh 1976-1978; Kaul and Sekhon 1977). A pigeonpea crop sown in June can vacate the field in time for sowing a following wheat crop. If the sowing is delayed beyond the first week of July, the yield of pigeonpea will be low and the wheat crop sowing will also be delayed.

Row and Plant Spacing

Optimum plant population is essential for obtaining maximum yield. A plant spacing of 20 cm at IARI, New Delhi (Bains and Chowdhury 1971) and 10 to 20 cm at Hissar (Anonymous 1979) gave maximum grain yields. In the same studies, row spacings did not differ significantly at IARI, New Delhi, but at Hissar and Ludhiana row spacings of 37.5 and 25 cm, respectively, gave maximum yields. Thus a row spacing of 25 to 40 cm and plant spacing of 20 cm is suitable for early and extra early varieties of pigeonpea.

Intercropping with Pigeonpea

The practice of mixed or intercropping has been common with long-duration varieties of pigeonpea under rainfed conditions. The possibility of intercropping in short-duration pigeonpea varieties has also been demonstrated at various locations. The studies conducted at Hissar, Ludhiana, and IARI (Singh and Singh 1976; Kaul et al. 1975; Saraf et al. 1975) have demonstrated that short-duration varieties of urd bean, mung bean, cowpea, and soybean can be successfully grown as intercrops in normal stands of early and extra early varieties without adversely affecting pigeonpea yields. Intercropping with sorghum, maize, and pearl millet has generally resulted in reduced yields of pigeonpea.

Fertilizer Application

On an average, the early-maturing pigeonpea removes about 115 kg N and 16 kg P/ha (Singh and Prasad 1976). Bains and Chowdhury (1971) reported significant increase in the pigeonpea yield with increasing levels of farmyard manure and phosphorus at IARI. Similarly, Singh et al. (1976) obtained significant response to phosphorus application and seed treatment with *Rhizobium* culture. The yield of pigeonpea has also been increased on farmers' fields with different inputs, such as seed treatment with *Rhizobium* culture, application of phosphorus, weeding, and plant protection; with the full package of practices the yield of pigeonpea doubled in comparison with the control (Anonymous 1978). Thus proper fertilization and plant protection is essential to harvesting a good crop of pigeonpea.

Rice Fallows and Winter Cropping

Varieties

A wide range of cultivars could potentially be used for the winter crop. In general, growth rates are slower because of lower temperatures, and development rates are faster because of shorter daylengths in winter sowings, so that all cultivars become shorter season when sown in the winter. The cultivars can be selected with some research in different agroclimatic regions where this type of pigeonpea cultivation is possible.

Sowing Time

Though pigeonpea can be sown at any time from September to November in rice fallows and as a winter crop, September sowing gave maximum yield under Bihar and Hyderabad conditions (Roy Sharma et al. 1979; ICRISAT 1977). Delaying sowing beyond September reduces yield even with higher plant densities. To enable sowing of the pigeonpea crop in time, short-duration varieties of rice, maize, and other rainy-season crops in the rotation should be sown.

Plant Population

For winter sowing and sowing in rice fallows, much higher plant populations should be used than in the normal season. Roy Sharma et al. (1979) have recommended 300 000 plants per ha for September sowing. However, plant population as high as 500 000 plants per ha were found suitable at Hyderabad (ICRISAT 1978). The higher densities are needed to raise canopy LAI to a level where effective interception of light can occur.

Fertilizer Application and Plant Protection

Fertilizer application is necessary for raising a good crop of pigeonpea, however, the levels of fertilizer will depend on thefertility status of the soil and on the previous crop. Exact requirements need to be worked out under different agroclimatic conditions. The incidence of diseases and insect pests will be low in the pigeonpea crop sown in winter and rice fallows. However, proper plant protection measures will be necessary.

Intercropping

When pigeonpea is used as an intercrop in coconut, banana, tapioca, sugarcane, etc., only the early and extra early varieties of pigeonpea should be used. The density, fertilizer application, and plant protection measures will depend on the nature of the main crop.

References

Agricultural situation in India, 1979. 34(7): 493-495.

ANONYMOUS, 1978. Operational research project on pulses in Mohendergarh district (Haryana), annual report 1978.

ANONYMOUS, 1979. Pigeonpea research in Haryana. Presented at the Workshop on Pigeonpea Research in India, April 1979, Dholi, Bihar, India.

BAINS, S. S., and CHOWOHURY, S. L. 1971. Agronomy of pulse crops. Pages 24-46 *in* New vistas in pulse production. New Delhi, India: Indian Agricultural Research Institute.

FARODA, A. S., and SINGH, R. C. 1976-78. Reports on kharif pulses, Haryana Agricultural University, Hissar, for 1976-78, Hissar, India.

GOPALAKRISHNAN, R. 1975. Pulse production and research and the scope for multiple and intercropping of pulses in Kerala. Indian Journal of Genetics and Plant Breeding 35(2): 300-302.

ICRISAT, 1977. Pigeonpea. Page 85 *in* ICRISAT annual report, 1976-77. India: ICRISAT, Patancheru, A.P. 502 324.

ICRISAT, 1978. Pigeonpea physiology. Pages 92-121 *in* ICRISAT annual report, 1977-78. India: ICRISAT, Patancheru, A.P. 502 324.

JESWANI, L. M. 1979. Pick a pulse to fit into your cropping pattern. Intensive Agriculture 17(3): 15-17.

KALYAN SINGH, and PRASAD, R. 1976. Effect of nitrogen, phosphorus and Rhizobium inoculation on protein content and nutrient uptake of pigeonpea. Indian Journal of Agronomy 21(3): 266-270.

KALYAN SINGH, PRASAD, R., and CHOWDHURY, S. L. 1976. Effect of nitrogen, phosphorus and Rhizobium inoculation on growth and yield of pigeonpea under rainfed conditions. Indian Journal of Agronomy 21(1): 49-53.

KAUL, J. N., and SEKHON, H. S., 1977. Annual report on pulses, Punjab Agricultural University, for 1976-77, Ludhiana, Punjab, India.

KAUL,J.N.,and SEKHON, H.S.,and DAHIYA, B. S. 1975. Intercropping studies with pigeonpea. Indian Journal of Genetics and Plant Breeding 35(2): 242-247.

LENKA, D., and SATPATHY, R. K. 1976. Response of pigeonpea varieties to levels of nitrogen and phosphate in Laterite soil. Indian Journal of Agronomy, 21(3): 217-220.

MAHAPATRA, I. C, PADALIA, C. R., and RAO, M. V. 1971. Suitable cropping patterns for eastern India. Pages 290-294 *in* Proceedings, Symposium on Science and India's Food Problem. ICAR, New Delhi, India.

MANDAL, R. C, and SINGH, A. P. 1971. Role of tuber crops in multiple cropping in Kerala. Pages 295-298 *in* Proceedings, Symposium on Science and India's Food Problem. ICAR, New Delhi, India.

NATARAJAN, M., and VITTAL, T. M. 1975. Promising pulse varieties for intercropping and multiple cropping in Tamil Nadu. Indian Journal of Genetics and Plant Breeding 35(2): 291-294.

PANNU, J. S., and SAWHNEY, J. S. 1975. Effect of arhar on the nitrogen requirements of the succeeding wheat in an intensive rotation. Indian Journal of Genetics and Plant Breeding 35(2): 253-256.

PANWAR, K. S., and MISRA, A. S. 1973. Recommendations on the agronomy of kharif pulses based on work done at UPIAS, Kanpur. Presented at the Workshop on Kharif Pulses, IARI, New Delhi, India.

PATHAK, G. N. 1970. Red gram. Pages 14-53 *in* Pulse crops of India, New Delhi, India: ICAR.

ROY SHARMA, R. P., THAKUR, H. C, and SHARMA, H. M. 1978. Potentialities of September sowing of red gram. Presented at the National Symposium on Intercropping of Pulses. IARI, 17-19 July 1978, New Delhi, India.

ROY SHARMA, R. P., THAKUR, H. C, and SHARMA, H. M. 1979. Red gram breaks the rule. Intensive Agriculture 17(3): 12-14.

SARAF, C. S., SINGH, A., and AHLAWAT, I. P. S. 1975. Intercropping of compatible crops with pigeonpea. Indian Journal of Genetics and Plant Breeding 35(2): 248-252.

SINGH, A., and SARAF, C. S. 1976. Report on kharif pulses for 1975-1976, IARI, New Delhi.

SINGH, SURINDER, and SINGH, R. C. 1976. Economics of mixed cropping in pigeonpea under Haryana conditions. Haryana Agricultural University Journal of Research 6(3,4): 171-175.

Mechanized Dry Seed Production of Pigeonpea

E. S. Wallis, D. E. Byth, and P. C. Whiteman*

Abstract

The potential for mechanized production of dry seed is discussed. This involves consideration of the limitations of existing germplasm with respect to mechanized culture and harvest, options for production systems as full, short, and off-season crops in the semi-arid tropics and the commercial potential of such systems.

The role of grain legumes in crop rotations is widely recognized and will be increasingly important as nitrogen fertilizer becomes more expensive. Compared with other field crops, the pigeonpea offers the following potential advantages in broad-scale mechanized farming: drought tolerance, low fertilizer requirement, perennial habit, good weed control, nonlodging habit, and nonshattering pods. However, its acceptability in mechanized farming may be limited because the crop is normally of long duration. Many cultivars are sensitive to photoperiod, making sowing time an important determinant of yield and plant size; loss of yield due to insect and disease attack can be severe; and the seed may require drying after harvest.

The early work (1970-73) on pigeonpea at the University of Queensland concentrated on forage production (Wallis et al. 1975). The emphasis has now shifted to mechanized dry seed production.

Dry Seed Production Systems

Production Systems for Cultivar Royes

Wallis et al. (1979a, 1979b) recently reported the development of a production system for a relatively late (110 days to flower, longest day planting at 28°S) cultivar released in Queensland, Australia, as cv Royes. This cultivar (originaily introduced from the West Indies and designated UQ-50) was initially identified by Akinola and Whiteman (1972) as a promising accession because it produced a relatively high yield of large (12 g/100 seeds) white seeds. It is botanically determinate, with the pods borne terminally at the top of the canopy, which assists in mechanized harvesting. Cv Royes also regrows well after harvest in favorable environments to give a ratoon yield often as good as or better than that recorded in the plant crop.

Flowering in cv Royes is sensitive to photoperiod and temperature (Turnbull, personal communication) so that phenological development is influenced by time of sowing. Spence and Williams (1972) recognized the importance of this form of response in restricting vegetative growth in the crop. They suggested that sowings in inductive photoperiods should be at higher densities to compensate for the reduced vegetative growth.

Although cv Royes has been evaluated at several sites in southeastern Queensland over a number of years, yields were promising only in the frost-free coastal belt, which constitutes approximately 3 million hectares in the undeveloped north of Australia (Nix et al., personal communication). The incidence of frost in the inland cropping areas restricted broad-scale production using this cultivar. Further, a high degree of management skills would be required by the farmer to obtain high yields, including the selection of optimum densities for particular sowing dates and the application of insecticides at critical stages of flower and pod development. In practice, the extension of these princi-

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ples to farmers has been difficult and often poorly followed.

Phenological development of cv Royes (and all short-day plants) is affected by photoperiod. The major effect is in the length of the preflowering, or vegetative, phase of growth. The practical importance of this response is in the different photoperiods perceived by the crop at different sowing dates and latitudes (Figure 1). As described by Wallis et al. (1979a, 1979b) this effect is manifested as reduced vegetative growth with increasing delay of sowing after the longest day (Table 1).

Plant height decreased markedly (from 217 to 73 cm) as sowings were delayed. This response has important practical significance to the production system:

1. To enable mechanized harvest of cv

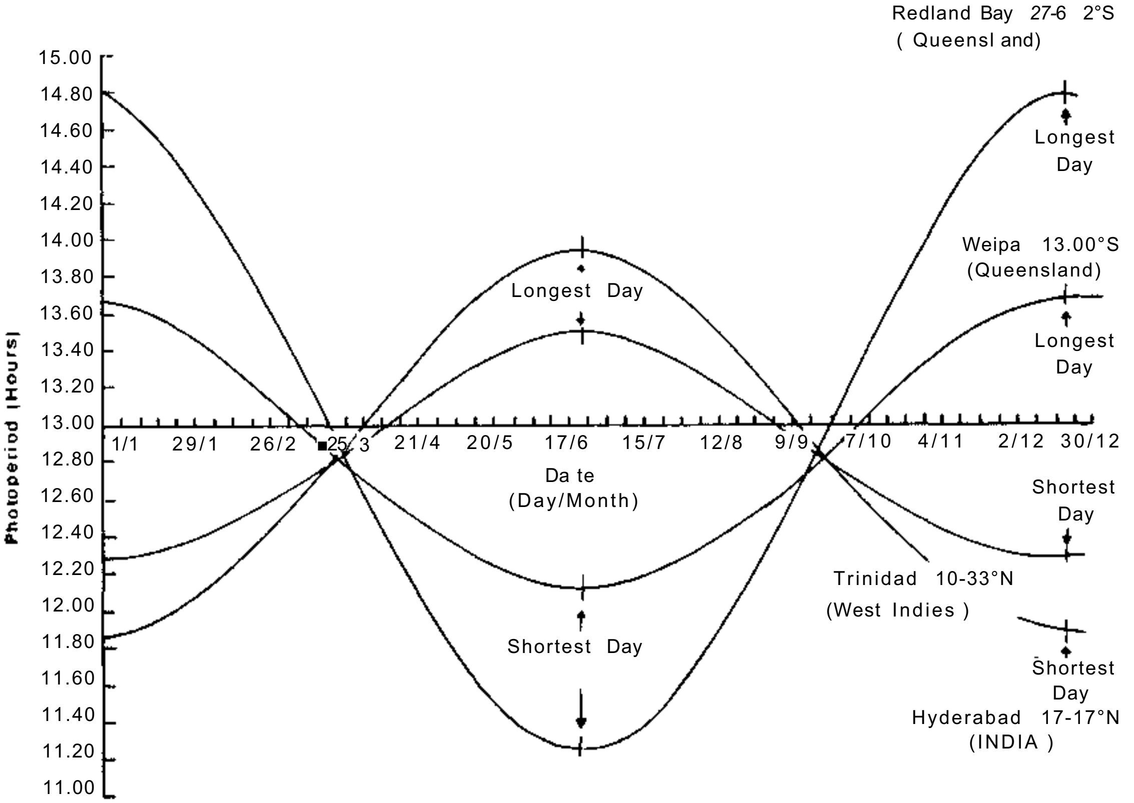

Figure 1. Photoperiod (including civil twilight) for Redland Bay, Weipa, Trinidad and Hyderabad.

Table 1. Effect of sowing time and density on plant height (cm) of pigeonpea cv Royes at Redland Bay (27°S).

Sowing date	Plant height at density (plants/ha) of				Sowing date mean
	10 000	18 000	33 000	110 000	
2 months prior to longest day	205	213	220	229	217
Longest day	155	168	172	177	168
2 months after longest day	71	72	74	74	73
Mean (effect of density)	144	151	155	160	

Royes, sowings should not be contemplated prior to the longest day, as excessive vegetative growth will cause considerable problems at harvest.

2. To maintain seed yield, the reduced vegetative growth at later sowings must be balanced by an increase in plant density.

Phenology and vegetative growth will be influenced by photoperiod x temperature interactions, and thus by sowing date and latitude. For example, Royes is approximately 10 to 15 days earlier flowering and 50 cm taller in Fiji (17°S), than for the same sowing date in Brisbane (27°S). This comparison is confounded by different latitude, but the major point is that the higher temperature during growth in Fiji led to more rapid flowering and increased vegetative growth.

The importance of synchronization of flowering (and hence of pod development) in this crop for mechanized production cannot be overemphasized. We have observed that greater synchronization of flowering occurs as sowing is delayed beyond the longest day and as plant density is increased. This is due in part to earlier flowering under the shorter daylengths and the reduced number of floral buds developed per plant as a result of the higher densities used to optimize yield. As a result of synchrony of flowering, insect pest management is required for a shorter period and is simpler to schedule; uniform pod maturity facilitates harvest. In fact, for those environments where temperature does not limit growth, such as Fiji, autumn (March) sowings may be optimal for crop management. Provided the plant is harvested and regrowth occurs in inductive conditions (prior to the end of August at 28°S) for cv Royes, flowering in the ratoon crop is rapid.

A summary of the recommended production system for cv Royes in subtropical Australia (Wallis et al. 1979a, 1979b) is as follows:

- Locate in frost-free areas.
- Grow on well-drained soils and weed-free seedbeds.
- Apply basal dressing of superphosphate.
- Check and correct any other mineral deficiencies, e.g., zinc.
- Inoculate seed with suitable *Rhizobium* e.g., CB 756.
- Use optimum sowing date and appropriate sowing density, which are most important (Table 2).
- Control pod-boring insects, particularly *Heliothis.*
- Harvest by "all-crop" header.
- Dry the seed when necessary.

The choice of sowing date and the appropriate density of sowing are the most important factors affecting production of cv Royes. The results of trials over 4 years at a number of locations have been used to formulate recommendations for sowing date-density combinations for cv Royes (Table 2).

The effect of sowing date on the phenology of cv Royes is such that, even within a particular month, sowing densities must be adjusted over the range indicated (Table 2) in order to obtain full canopy development and optimum seed yield. For example, 6 kg/ha of seed is required for early January sowings and 12 kg/ha for late January sowings. These figures are based on a seed size of 12 g/100 seeds and 100% germination, and would have to be adjusted for the germination, purity, and seed size of particular seed lots. For irrigated sowings, higher plant densities are required for optimal yield. The limited information available suggests that approximately 200 000 plants/ha is optimum for fully irrigated crops sown in January and Feb-

Table 2. Recommended sowing data-dansity combinations for dryland cv Royes in subtropical Australia.

Sowing density	Month of sowing					
	December (Longest day)	January	February	March		
Plants/ha	35 000-50 000	50 000-100 000	100 000-150 000	250 000		
Interrow space (cm)	75	75	75	75	50	25
Intrarow space (cm)	40-26	26-13	13-9	5	8	6
Kg/ha seed (100% germination)	4.2-6	6-12	12-18	30	30	30

ruary. The interrow space of 75 cm is chosen to enable ease of interrow cultivation for weed control. For plantings after late January, it is recommended that, wherever possible, the interrow space should be reduced to 50 cm (or 25 cm for March sowings) with a corresponding adjustment in intrarow spacing to maintain the nominated densities. Narrowing the interrow spacing assists in obtaining closure of canopy before flowering, which is essential for the attainment of high seed yield. Further details on the cultural practices recommended for southeastern Queensland are reported by Wallis et al. (1979a).

Mechanically harvested seed yields using this production system are reported in Table 3. Higher yields (up to 4500 kg/ha per year) have been obtained from small hand-harvested experimental plots (Wallis and Whiteman 1976).

Using this production system, normal "all crop" headers can harvest the crop. Drying of the seed may be necessary. Defoliation of the crop prior to harvest is possible, and this reduces or avoids the need to dry seed after harvest. In our experience, regrowth of the plants is unaffected by defoliation prior to harvest.

A ratoon crop can be harvested from the same plants and often produces a seed yield as great as the plant crop (Table 3). Time of harvest of the plant crop is an important factor in determining the time of harvest of the ratoon. Harvest must be completed in inductive photoperiods to ensure rapid flowering in the ratoon and early harvest.

Other Models of Dry Seed Production

Culture of cv Royes in subtropical environments is restricted by its photoperiod responsiveness, which places the reproductive phase in the coldest, driest period of the year. This restricts the crop to warmer, frost-free, well-watered environments. Two approaches may be taken to avoid these limitations.

Selection of Earlier Flowering Cultivars

A number of breeding lines and accessions have been introduced to this program that are earlier flowering than cv Royes but have similar plant habit and acceptable seed quality. The phenology of this material is influenced by photoperiod and temperature, as it is with cv Royes; thus it will benecessarytodocumentthe sowing date x density interactions for these lines in order to develop optimal production systems. The potential of this material for seed yield has yet to be determined. However, such lines will flower up to 1 month earlier than cv Royes from the same sowing date, will probably mature 40 to 50 days earlier. This will greatly expand the area suitable for this crop in subtropical Australia.

Material that shows potential includes selections from cv Royes, introductions from ICRISAT (ICP-6, advanced lines from crosses involving Prabhat, ICP-6997, Baigani, and Pusa Ageti), from the University of the West Indies UWI-12, UWI-17, UWI-42, and advanced breeding lines F_6 (1 x 1-2), (8 x 1-1), and from the

Table 3. Mechanically harvested yields of cv Royes at Redland Bay (27°S) southeastern Queensland, Australia.

Sowing date	Density (plants/ha)	Yield (kg/ha) on 238/1977	Ratoon yield[b] (kg/ha) on 26/1/1978	Total yield (kg/ha/year)
9 Dec 1976	21 900	1010	2000	30 10
	47 600	1710	2000	37 10
	78 400	1670	1900	35 70
28 Jan 1977	47 600	1130[b]	1600	27 30
	88 900	9 10	1600	25 10
	111 000	1250	1800	30 50

a. Hand-harvested subplots.
b. Harvested prior to maximum pod maturity because harvester was only available on 23 Aug 1977.

Ministry of Agriculture of Jamaica (C-322). The yield potential and plant characteristics of these lines will be evaluated in 1980-81 (Wallis et al. 1981a).

Selection of Photoperiod-insensitive Germplasm

The major benefit of the photoperiod sensitivity is that later sowings can be used to restrict vegetative growth and induce synchronization of flowering. These advantages can also be gained by the use of early-flowering lines that are insensitive (or nearly so) to photoperiod at the latitude of interest. Such material will have relatively constant phenology across sowing dates, provided temperature is not limiting. Since early insensitive lines will have a shorter preflowering phase than cv Royes regardless of sowing date, they will be vegetatively smaller and need to be sown at greater density in narrower rows to maintain productivity. This principle of compensating for reduced plant size with increased plant population has been demonstrated in other species (Lawn et al. 1977).

The progeny by self-pollination of an off-type plant from ICP-7179 has been shown to be early flowering (approximately 55 days from sowing) and insensitive to photoperiods up to 16 hours. This material allows the development of alternative production systems for this crop. For example, this material could be expected to complete a crop cycle in around 110 days anywhere in the latitude range of ± 35°, provided favorable temperatures exist. Sowings would not have to be restricted to shortening days, and various cropping strategies can be devised. In one such system (diagrammed in Figure 2), spring sowings of insensitive cultivars made as soon as soil temperature favors germination (Sept/Oct) will flower rapidly, and mature seed may be harvested in January. These plants will ratoon and produce further seed crops, provided the plant stand is maintained and temperature does not restrict growth. Insensitive material could be sown at any time when temperature does not limit growth and development.

The material identified from ICP-7179 has been selected and purified to provide breeding material for a plant improvement program aimed at developing photoperiod-insensitive, early-flowering pigeonpeas suitable for mechanized harvesting (Figure 3). This material was initially considered unique in its nonresponsiveness to photoperiod; however, we have now identified a much wider range of genetic material insensitive or nearly so to 16-hour days that can be used in this program (Wallis et al. 1981b).

The agronomic performance of a bulk population of the insensitive material derived from ICP-7179 has been evaluated in several trials using relatively high plant densities in 20- and 25-cm rows. Regardless of sowing date, flowering is quite synchronous and occurs in 55 to 60 days from sowing (Table 4).

Dry seed yields (Table 5) were high in the plant crop and ratoon. Seed yield in the ratoon of the September sowings was high even at low density. This indicates that in that ratoon, plants were able to produce sufficient vegetative growth to provide the basis for high seed yield even when plant population in the plant crop was suboptimal. This is important in mechanized systems, as plant losses due to damage at harvest are inevitable. Seed yields from crops ratooned during the coolest and driest period of the year (June-January) were poor, but this is probably a function of environmental limitation at that site.

Pure lines derived from the insensitive bulk population have been derived and evaluated in small plot trials. Seed yields up to 4500 kg/ha on the plant crop and 3500 kg/ha in the first ratoon have been measured. This suggests that production systems based on insensitive cultivars may have significant potential in many areas.

However, this material has relatively low numbers of seeds per pod and small (7 g/100 seeds) brown seeds that probably have low market attraction and are less desirable for dhal manufacture. The plant improvement program summarized in Figure 3 is aimed at producing improved germplasm forthis system of production. In this context, existing new material derived from a cross (ICP-8504 x Prabhat) x ICPL-10 was introduced from ICRISAT in 1979. Selfed progeny of the introduced material (open-pollinated seed from triple-cross F_1 plants, selected to have six or more seeds per pod and flowering in less than 70 days in the F_1 at Hissar in northern India), were evaluated in Australia as F2-derived progenies in the F_3 in 1979-80 (Byth et al. these Proceedings). Many lines have large seeds (up

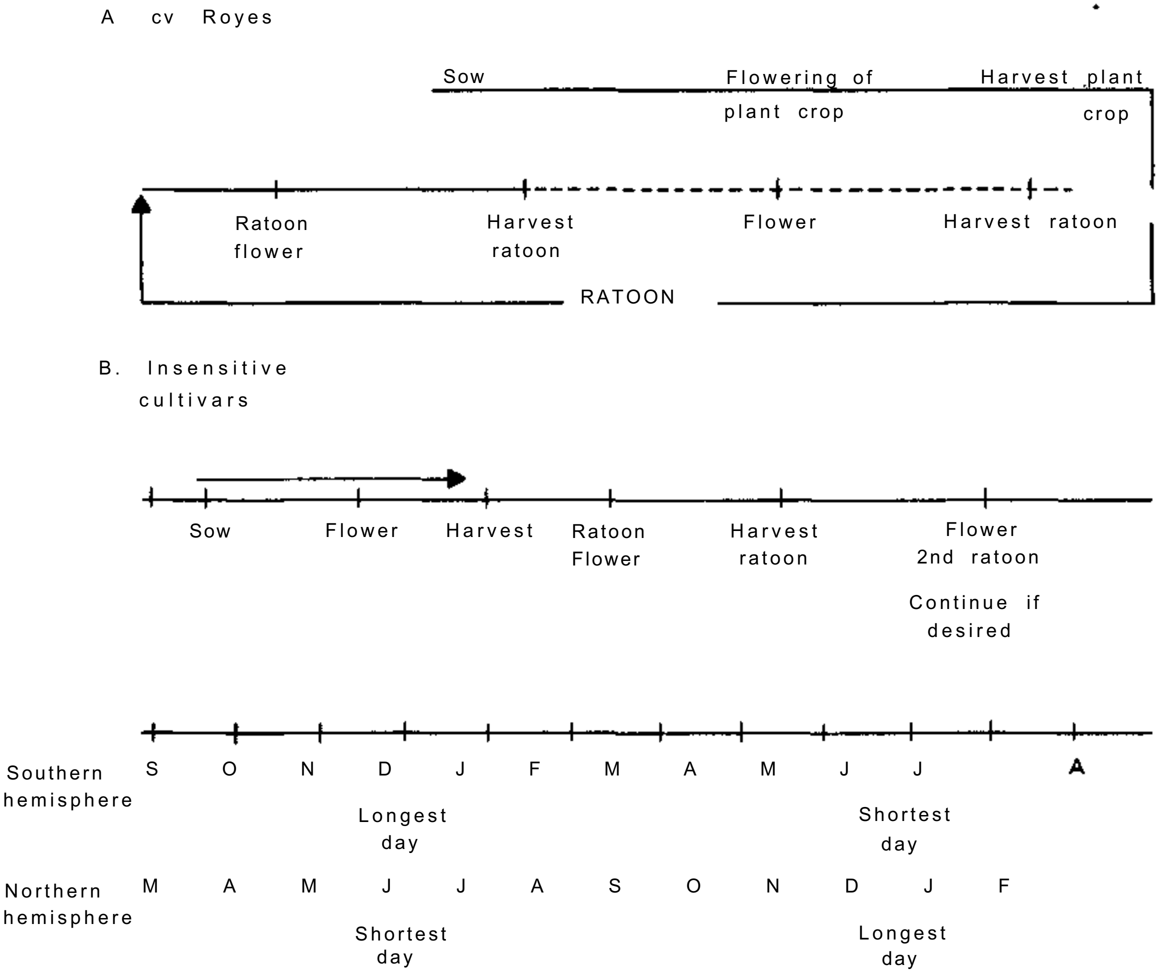

Figure 2. Dry seed production systems for pigeonpea.

to 15 g/100 seeds) and flower in less than 60 days. This material is considered to be photoperiod insensitive, and will be tested as F_3-derived lines in F_5 during 1980-81. Relatively high population densities (about 300 000 plants/ha) will be required to maximize yield. Thus, substantial advances can be made for seed yield in short-season material suitable for mechanized production, and this genetic material has potential value in other areas as well.

Crop Management for Dry Seed Production

As indicated earlier in this paper, plant density and arrangement have substantial influence on performance for seed yield, and there are large sowing date x plant density/arrangement interactions for yield of photoperiod-sensitive cultivars. The uniformity of plant spacing within the row influences plant development and seed yield, and precision sowing equipment should be used to attain the desired plant stand. Inadequate plant density and uneven distribution of plants can negate much of the value of other cultural inputs.

Although the closed canopy of pigeonpea effectively suppresses weed growth, weed competition can have serious effects during early growth of the crop. Methods of weed control in broad-scale agriculture of pigeonpea in the tropics and subtropics require further investigation. Preliminary observations in

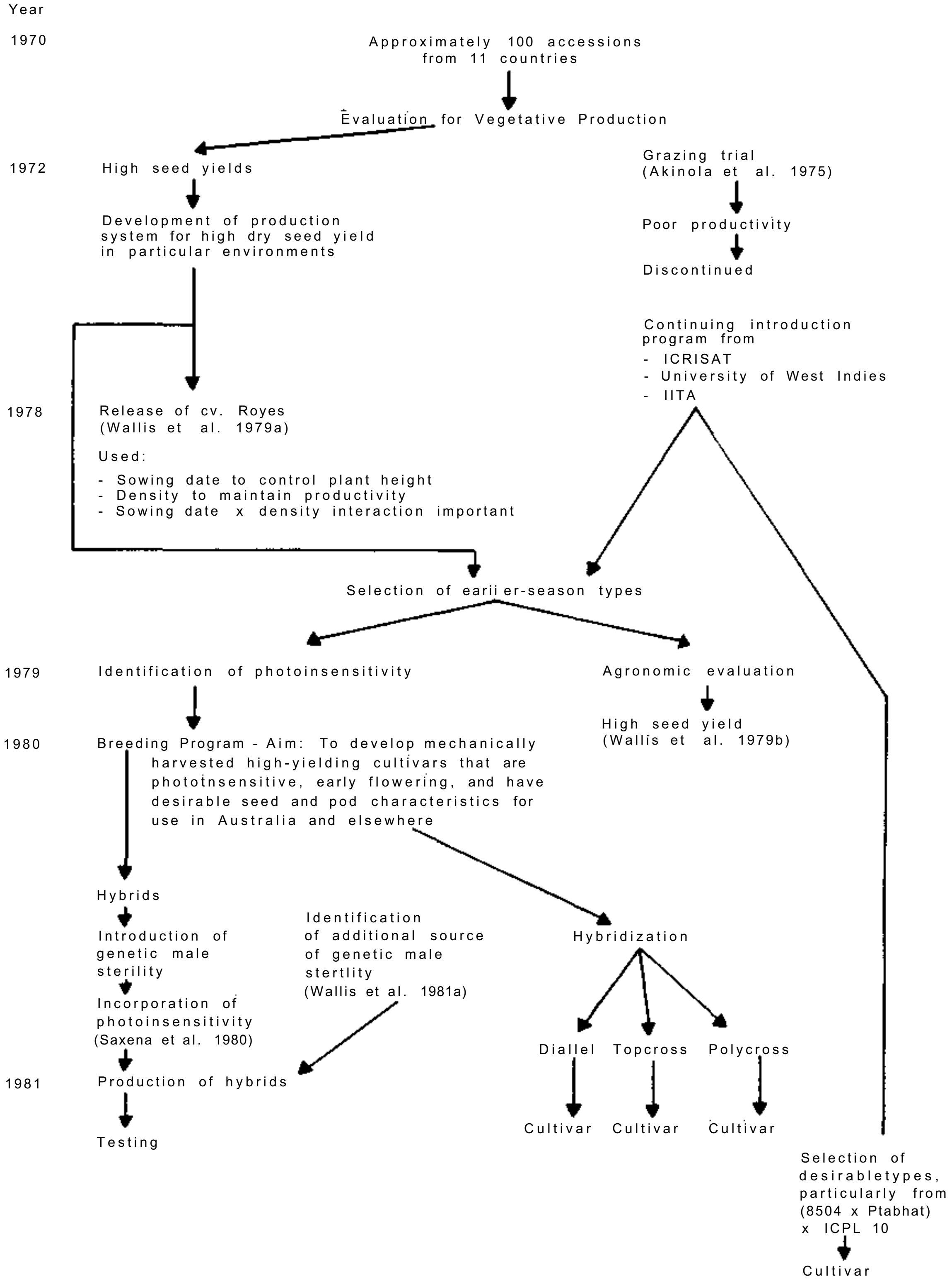

Figure 3. Summary of University of Queensland Pigeonpea Program.

Australia and Fiji indicate that the use of treflan (trifluralin) at the recommended rate for a particular soil is often detrimental to pigeonpea growth. Lower levels of active ingredient do not affect the pigeonpea but may also be less effective on the weed species. Identification of suitable weedicides is a high priority, particularly for the early-flowering cultivars, which need to be sown at high density in close rows (20-25 cm) where mechanical weed control is not possible.

The problems of insect control in pigeonpea have already been discussed. Chemical control is inevitably an integral component of management, and can be justified economically in relation to the potential for seed yield. However, the development of effective integrated pest-management programs that will allow effective scheduling of insecticide application is an important research priority. Biological control agents need to be studied in detail.

The retention of green vegetative material on pigeonpea plants at pod maturity causes relatively few problems in mechanical harvesting, and reasonably clean seed samples can be obtained from commercial combine harvesters. However, the seed becomes wet during passage through the machine and must be dried immediately to prevent deterioration. This imposes an additional cost of production and handling problems that may restrict acceptance of the crop. Chemical defoliation prior to harvest is possible using paraquat and/or diquat,

Tabla 4. Time to flowering and harvest of dry sead of photolnssnsitive plgaonpaa for two sowing datas at Radland Bay, Australia (27°S).

Sowing date	Days to 50% flowering	Days to harvest
26 September		
Plant crop	56	112
Ratoon crop	38	132*
19 January		
Plant crop	58	132[3]
Ratoon crop		

a. Days to 50% maturity; maturity delayed due to cool weather, and variability in habit of ratoon plants.

Table 5. Mean seed yleid (kg/ha) of 1977-78 sowing date-density trial of photoperiod insensitive pigaonpaa at Radiand Bay, Australia (27°8).

Sowing date	Density (plants/ha)	Arrangement (cm)	First harvest (Jan 1978) Actual	First harvest (Jan 1978) Potential	Second harvest (June 1978)	Third[b] harvest (Jan 1979)	Total yield
26 Sept 1977	100 000	25 x 40	1320	1800	2400	305	4025
	200 000	25 x 20	1970	2470	2620	170	4760
	300 000	25 x 13	2130	2510	2460	205	4795
	400 000	25 x 10	2580	2970	2710	220	5510
	500 000	25 x 8	2630	3020	2450	60	5140
			June 1978		Jan 1979*	Apr 1979	Total yield
19 Jan 1978	100 000	25 x 40	1610		420	925	2955
	200 000	25 x 20	2180		670	1160	4010
	300 000	25 x 13	2670		760	880	4310
	400 000	25 x 10	2400		840	1350	4590
	500 000	25 x 8	2890		880	1240	5010

a. Actual yield from hand-harvested plots. Potential yield Includes estimates of seed lost to *Heliothis* damage.
b. Low yield due to regrowth during coolest, driest period of the year and high plant mortality.

and this reduces or eliminates the seed drying. However, these chemicals are not particularly effective, and the cost is high and commercially unacceptable. The identification of chemicals that defoliate pigeonpea effectively but do not interfere with regrowth would be a major contribution to efficient mechanized harvesting.

Ratoon cropping of pigeonpea appears to be a realistic commercial option in certain areas, because of the high seed yield potential and reduced costs of production for such crops. There is considerable interest by farmers in this possibility. However, preliminary studies have suggested that ratooning ability and plant habit of the ratoon crop are distinct genetic characteristics. Management of ratoon crops to maintain plant density and provide protection from insects needs to be considered carefully.

Because of its perennial habit and ability to withstand and recover from periodic moisture stress, the pigeonpea has potential *as a* dual-purpose crop for seed production and grazing in large areas of subtropical and tropical Australia. In situations where environmental stress (low rainfall, insect attack, etc.) reduces the probability of economic seed yield, the crop provides valuable grazing during both the plant and ratoon crops. Indeed, controlled grazing could be an integral part of crop management. Provided plant stand is not reduced by grazing or disease, grazed areas could be ratooned for subsequ ent seed crops. Aspects of this form of use are discussed by Whiteman and Norton in a paper at this workshop.

Conclusion

The development of early-flowering photoinsensitive material for mechanized agriculture is proceeding, and promising results have been obtained. This has important implications in broadening the range of adaptation of pigeonpea, and in simplifying agronomic practices across latitudes and sowing dates. Extension of the production systems for insensitive cultivars to farmers, and implementation in practice, will be easier than for the cv Royes-type production system.

In Australia, all field crops grown for seed production are managed to provide a single harvest of the plant crop. This form of crop adaptation may be desirable or obligatory in temperate areas, but its relevance in the tropics is debatable. Indeed, in view of the diversity and variability of the seasonal environment in the tropics and subtropics and the variability of timing of biotic challenges (insects, disease), it is arguable that a perennial growth habit has significant advantages. This may be particularly so where the growth habit combines botanical determinacy and reproductive indeterminacy, as in pigeonpea. This model allows significant options in management, depending on the particular production environment, including such factors as flexible sowing dates, tolerance of intense periodic stress, and ratoon cropping. The importance of thesefactors, particularly the last, in the economics of production is self-evident.

Among the grain legumes, pigeonpea appears to be particularly well adapted to broad-scale agriculture under rainfed conditions in the semi-arid tropics and subtropics. Production can be mechanized, and the extension of pigeonpea culture to mechanized production areas throughout the world will depend on cost of production and marketability. In Australia, the largest market will be for commercial stock feed (particularly in compound rations for pigs and poultry) although a global market exists for the seed for human consumption. The extent of acceptance of the crop by farmers will inevitably rest on the economics of production.

Acknowledgments

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References

AKINOLA, J. O., and WHITEMAN, P. C. 1972. A numerical classification of *Cajanus cajan* (L.) Millsp. accessions based on morphological and agronomic attributes. Australian Journal of Agricultural Research 23: 995-1005.

AKINOLA, J. O., BIRCH, C. J., WHITEMAN, P. C, and WALLIS, E. S. 1975. Grazing evaluation of pigeonpea (*Cajanus cajan* [L] Millsp.) at Mt. Cotton, Southeastern Queensland. Proceedings, Australian Conference on Tropical Pastures. Townsville, Queensland, Australia, 2(7): 46-53.

BYTH, D. E., SAXENA, K. B., and WALLIS, E. S. 1981. Evaluation of a population of early maturing pigeonpea lines derived from a triple cross introduced from ICRISAT. *In* Breeding, Volume 2, these Proceedings.

LAWN, R. J., BYTH, D. E., and MUNGOMERY, V. E. 1977. Response of soybeans to planting date in Southeastern Queensland. III. Agronomic and physiological response of cultivars to planting arrangements. Australian Journal of Agricultural Research 28: 63-79.

SAXENA, K. B., WALLIS, E. S., and BYTH, D. E. 1980. Development of a photoinsensitive early flowering male sterile line of pigeonpea *(Cajanus cajan* [L.] Millsp.). Available from authors on request.

SPENCE, J. A., and WILLIAMS, S. J. A. 1972. Use of photoperiod to change plant design. Crop Science 12(1): 121-122.

WALLIS, E. S., WHITEMAN, P. C, and AKINOLA, J. O.1975. Pigeonpea *(Cajanus cajan* [L] Millsp.) research in Australia. Pages 149-166 *in* Proceedings, International Workshop on Grain Legumes. ICRISAT, 13-16 Jan 1975, Hyderabad, India.

WALLIS, E. S., and WHITEMAN, P. C. 1976. Pigeonpea *{Cajanus cajan* [L.] Millsp.): A potential crop for Queensland. Proceedings, Australian Oilseeds and Protein Grains Research Conference, Toowoomba, Queensland, Australia 2(b): 88-89.

WALLIS, E. S., WHITEMAN, P. C, and BYTH, D. E. 1979a. Pigeonpea. A new crop for Queensland. Queensland Agricultural Journal 105(6): 487-492.

WALLIS, E. S., WHITEMAN, P. C, and BYTH, D. E. 1979b. Pigeonpea (*Cajanus cajan* [L] Millsp.) production systems in Australia. Presented at the Regional Workshop on Tropical Grain Legumes, University of the West Indies, St. Augustine, Trinidad.

WALLIS, E. S., BYTH, D. E., and SAXENA, K. B. 1981a. Flowering responses of thirty-seven early maturing lines of pigeonpea. *In* Breeding, Volume 2, these Proceedings.

WALLIS, E. S., SAXENA, K. B., and BYTH, D. E. 1981b. A new source of male sterility in pigeonpea. *In* Breeding, Volume 2, these Proceedings.

Discussion — Session 1

Balasubramanian:

September has been found to be the optimum sowing time for postrainy pigeonpea; how will this fit in with the rainy-season crop in rainfed sequence cropping?

Roy Sharma:

The September-sown pigeonpea can be grown in sequence with maize (GS-2), early paddy (Pusa 33, Pusa 2-21), paddy nursery, jute for fiber, or minor millets. In flood-prone areas, pigeonpea can be sown after the flood recedes. Also, where the kharif crop fails, rabi pigeonpea can be sown, but sowing beyond the first fortnight of September reduces yield.

Grewal:

I agree with the concept of rabi sowing of pigeonpea, but Bahar and Basant are highly susceptible to *Altemaria* blight, which is both seedborne and airborne. The entire rabi crop in Bihar can be wiped out by this disease and farmers may have to pay heavily. We should therefore go slow with rabi pigeonpea until we have varieties resistant to *Altemaria* blight.

Roy Sharma:

Cvs Bahar and Basant were found to have the most potential for rabi cropping, but we found they were susceptibleto/*Alternari*a in 1979-80. Other cultivars among the early and medium-maturity groups could be examined. Screening for *Alternaria*-resistant lines is in progress.

Katiyar:

What was the level of pod-borer incidence at different dates of sowing?

Roy Sharma:

Pod-borer incidence increased slightly with delay in sowing.

De:

Do you have any information on micro-climatological parameters? These are very important and need to be examined.

Roy Sharma:

We do not have any information yet, but our entomologists are now trying to collect it.

Bhatnagar:

Postrainy-season pigeonpea in Bihar and other places is being evaluated at the researcher's level of protection and management. Both insect pests and disease incidence are likely to be important influences on rabi pigeonpea in any region. Evaluation of this system under the farmer's level of technology would be more realistic.

Roy Sharma:

These aspects are being considered in the on-farm tests.

Lal:

The reasons Dr. Sharma has given for smaller grains in rabi pigeonpea as compared with the June-sown crop are not convincing. Our experience showed that higher yield in rabi pigeonpea is due to a higher number of pods per unit area, more grains per pod, and bolder grain. The duration of winter pigeonpea is shorter because of reduction in the vegetative phase but not in the reproductive phase.

Roy Sharma:

As sowing is delayed, seed development and maturity coincide with high easterly winds, which might affect seed size slightly, about 5 to 6 g per 1000 seeds. The higher yields are mainly due to the higher number of pods per unit area and more seeds per pod. The environmental conditions and the variety used might also influence the seed size.

Umaid Singh:

Dr. Roy Sharma mentioned that there was no difference in the cooking quality of June- and September-planted pigeonpeas. Surveys we conducted in some parts of Uttar Pradesh indicated that farmers preferred kharif-grown pigeonpea.

Parpia:

What is the effect of April or September sowing on (1) resistance to postharvest infestation; for instance, husk thickness, and (2) milling quality, especially the adhesion layer between the husk and kernel and the effect on subsequent cooking?

Roy Sharma:

We have done no work on these aspects yet, but we are planning to initiate it this year.

Sheldrake:

Cooking tests organized by the Pulse Physiology Program at ICRISAT have shown that there is little noticeable difference in cooking qu ality or taste between the rainy- and postrainy-season crops. The milling recovery is also almost the same.

Joshi :

Decrease in seed weight from June- to September-planted crops is different in different varieties; this may be examined from the climatological standpoint, e.g., temperature and humidity during flowering and pod filling. There is need to breed for erect branching in both rainy and postrainy-season crops. For postrainy-season pigeonpea, breeding for increased seed weight and frost resistance may be undertaken. NP(WR)-15, which has an erect branching habit and wilt resistance, might be used as a donor for frost resistance. Intercrop comparisons in yield and income levels also need to be made between April-planted pigeonpea and other rainy-season crops like maize, cotton, etc.

Roy Sharma:

Cultivar Bahar, recommended for postrainy-season planting, is erect in habit The decrease in seed weight in early and medium cultivars is negligible, but is noticeable in late cultivars because the seed size decreases with the shortened grain-development period.

B. M. Sharma:

Intercropping of mung bean in April-planted pigeonpea cv T-21 is becoming popular in western Uttar Pradesh. This can be followed by wheat in the postrainy season. April planting of pigeonpea with early varieties is expected to increase from 12 000 ha recorded last year to 140 000 ha this year in Uttar Pradesh, Punjab, and Rajasthan.

Panwar:

This is true; yet there is scope to improve this system further by working out optimum water and population requirements and improving the harvest index.

B. M. Sharma:

In several areas of U.P., urd bean is being intercropped with postrainy-season pigeonpea, which can give yields upto 2500 kg/ha. Dr. Roy Sharma has presented for the same variety higher yields at Dholi than at Ranchi, which I think is due to better soil moisture conditions in Dholi. Is there any information on the response of postrainy-season pigeonpea to irrigation?

Roy Sharma:

In northern Bihar, postrainy-season pigeonpea did not respond to irrigation because of the high moisture in the soil profile; however, in southern Bihar, where moisture is limiting, a positive response has been obtained.

Sanghi:

With the existing high price of pigeonpea, there is a tendency to take a higher proportion of it in the cereal/pigeonpea system. There is also a trend towards pure pigeonpea as an alternative crop in red soils in the rainy season; this necessitates development of agronomy for sole pigeonpea.

We noticed larger reductions in sorghum yields (20 to 25%) in farmer's fields on black soils. In such a situation, it is not clear whether to recommend intercropping instead of double cropping. Perhaps intercropping is preferable to double cropping only in situations where draft power and labor are limiting.

Willey:

I agree that farmers seem to be including higher proportions of pigeonpea. I would like to think that this reflects the efforts of research workers, but I suspect that a favorable price is the real reason. Our experience on the effects of soil type is rather different from yours. We have found that it is on the Alfisols, especially in dry years, that the sorghum yield is decreased; this is offset by (and may be caused by) higher pigeonpea yields.

The emphasis on full cereal yield in earlier studies, is in the right direction, because it relates to the farmers' requirement, especially when the yield levels of the cereal are low. But when we have improved the cereal yield to more than 3000 kg/ha, we should be happy with 80 to 85% yield of cereal in intercropping.

Tahiliani:

Dr. Willey has pointed out the effect of intercropping and mixed cropping on higher pest incidence in late-maturing pigeonpeas. In the last 3 years, we have also seen unseasonal rainfall favoring pest attack and flower drop. Climatological factors can be important in limiting pigeonpea production.

De:

The unseasonal rainfall effect is a local phenomenon, but the change in the pest complex with the change in cropping system is important and should be monitored properly.

Saka:

in Malawi, farmers grow pigeonpea intercropped with cassava; pigeonpea is ratooned, and the cassava stays in the field for 2 years. Seed yields of about 600 kg/ha have been reported for pigeonpea, and its stems are used as fuel. Both the crops do well in poor soils and pest problems seem to be low. Probably these are the reasons why farmers intercrop these two long-season crops; however, more research on this system is needed.

Shivashankar:

Dr. Willey has mentioned double cropping in rainfed farming. I feel this is feasible only on black soils and where rainfall is well distributed. On red soils, a long-duration crop of pigeonpea intercropped with groundnut, mung, urd, or cowpea can be promising. If crops are established early by dry sowing, yields up to 2500 kg/ha of pigeonpea and 500 to 800 kg/ha of the intercrop are not uncommon. Double cropping is risky due to difficulties in establishing the second crop, and it requires extra fertilization.

Willey:

I agree with your comments on the risks associated with double cropping and also on the problem of having to provide fertilizer for the second crop. But of course we may find that growing a high yield of intercrop pigeonpea as a "second" after a cereal may ultimately lead to the need for more fertilizer.

Pareek:

Low temperatures in winter might affect nitrogen fixation in postrainy-season pigeonpea. Do you have any information on nodulation and N-fixation in your studies?

Roy Sharma:

Good nodulation was observed in the September-sown crop, but nitrogen-fixation activity needs to be examined.

Avadhani:

At the University of Agricultural Sciences, Bangalore, when intercropped pigeonpea (cv TT-7) was ratooned, a severe infestation of Agromyzid fly was noted. The pest complex needs to be kept in view while developing ratoon cropping systems.

Wallis:

I agree that the pest complex is very important in both plant and ratoon crops. This area is poorly researched and requires further investigation.

Sheldrake:

in this session, we have heard about three aspects of pigeonpea cultivation: extension to new areas, postrainy-season cropping, and exploitation of the perennial nature of the crop. At ICRISAT in the Pulse Physiology Program, a rabi-kharif-rabi cropping system is being tested in which pigeonpea is just taken as a rabi crop and then left in the field after harvest of pods. Then it survives the summer and goes onto produce a good kharif crop, which can be then ratooned to give a further yield in the rabi season. This new cropping system may be of considerable value in areas where fields are left fallow in the kharif season. The main problem may be the buildup of diseases such as sterility mosaic, grazing by cattle in the summer, and pests. However, the pigeonpea may survive grazing, and sterility mosaic-resistant material is now available. At present, a trial is being carried out jointly by ICRISAT and Andhra Pradesh Agricultural University at Sangareddy, using a sterility mosaic-resistant cultivar; this should give us some idea of the potential of this new system.

Joshi:

I have three comments:

1. Photo- and thermo-sensitivity seem very important considerations for pigeonpea breeders and agronomists;
2. Ratooning of pigeonpea would be relevant only in sole cropping, the possibility of which is limited to a few areas.
3. Pigeonpea and other legumes are known for their nitrogen fixation. But what role do they play in mobilizing unavailable (fixed) phosphorus in the soil? This is important in India, for our phosphate problem is more acute than the nitrogen problem. While long stalks of pigeonpea may appear desirable as fuel, it would be interesting to know how much phosphorus is removed from the soil by them. It is equally important to consider how much phosphorus the leaf fall from pigeonpea and other legumes adds to the soil.

Kanwar:

I would like to know from Dr. Faroda whether he has some data on the yields of pigeonpea and wheat and the amount of irrigation used in the two systems so that they can be judged in the proper perspective.

Faroda:

At present I do not have data to compare. But experiments are in progress to compare cotton-wheat, pigeonpea-wheat, pearl millet-wheat, and other rotations at Hissar and IARI. The fertilizer and water requirement aspects are also being taken into consideration for evaluating the different rotations.

Onim:

Mechanized dry seed production requires very high inputs. Can grain yields of about 3000 kg/ha from plant and ratoon crop ever be economical?

Wallis:

In the Australian context, with the price of sorghum at around $100/tonne and soybean about $250/tonne, pigeonpea for stock feed should be priced at $150/tonne. Farmers would return a satisfactory profit at this price. For high-priced human consumption markets, returns to farmers would be high also.

M. C. Saxena:

Could you give us an idea of the magnitude of losses of grain in mechanized harvesting?

Wallis:

With careful adjustment of drum speed and spacing between rasp bars and drum, losses in machine harvesting are low. The use of desiccant sprays to reduce the vegetative material passing through the machine would further reduce losses.

Kanwar:

On research stations, crops are considered as separate entities; in practice, however, they are parts of a multiple-cropping system. Thus, whenever a change in practice is suggested, the entire new system should be evaluated against the conventional one.

For example, how will kharif pigeonpea affect the wheat crop in northern India? How does the rotation compare with the traditional maize-wheat, millet-wheat, or rice-wheat under irrigated and rainfed conditions?

Similarly, when we consider early planting of pigeonpea, we must also consider what crop it replaces — e.g., cotton or sugarcane — and how it compares with that crop. But it is essential to examine whether pigeonpea is the best available crop or whether wheat or some other crop performs better. Data of at least two or three seasons should be presented so that we have operated and evaluated a continuous system. Only such data can provide information on pest and disease complexes.

Baldev:

We also have some varieties that can be mechanically harvested but blockage of the drum is a problem. Can you give us some idea how to overcome this?

Wallis:

As with all grain legume crops going through a mechanized harvester, we must keep drum speed very slow and perhaps increase the distance between the bar and the drum itself. But we have very little blockage in our experience. It is important to sow the crop at high density and reduce stem thickness, as thick stems may cause some trouble. Dr. Byth might comment on this.

Byth:

Machines differ greatly in their threshing characteristics. It is possible that the machine you used had a big toothed drum. For almost all pulses, a rasp bar drum is a far better proposition. Ground speed should be well controlled, but the important point is that in mechanized harvesting we should pass as little green material as possible into the machine. This calls for top-podded determinate and cluster types of pigeonpea.

Shah:

Rabi pigeonpea has been grown in Gujarat traditionally; however, the area is restricted and localized in Surat and Bulsar districts. Some cultivators in villages around cities like Ahmedabad and Baroda have also started planting pigeonpea in February-March, and the green pods are being sold as vegetables in June-July at a premium price.

Goswami:

Field experiments with pigeonpea to determine the effect of sowing time, season, or mixed cropping should also include collection of data on nodulation, since this can influence nitrogen fixation in pigeonpea.

Byth:

I support that. It is also extremely important that site characteristics be carefully documented at all test locations if a clear understanding of adaptation is to be obtained. For instance, at Hissar in the 1980-81 season, total precipitation was low (220 mm) and ceased by 18 August, prior to flowering; yet in December the crop is still green, active, and not wilting. One must therefore conclude that the crop is tapping a water table. Without knowledge of site characteristics, one would be encouraged to believe that the crop grew extremely well under extremely dry conditions. Without proper site characterization, one would come up with wrong conclusions on adaptation.

Misra:

In discussing various farming systems, the speakers have omitted one, i.e., raising pigeonpea on paddy bunds. This is practiced by farmers in Orissa, parts of Madhya Pradesh, Bihar, and West Bengal. Pigeonpea is planted thickly on bunds; but it often does not give good yields. Is there any information available on such a system? If not, some work needs to be done on this in order to get good yields.

Roy Sharma:

This practice has been in vogue for a long time. However, two to three seeds per hole at 25 to 30 cm can be planted and where more than one row is possible, rows can be established at 40 cm.

Kulkarni:

Regarding sorghum pigeonpea intercropping, it is known that sorghum requires more nitrogen, whereas pigeonpea requires more phosphorus. Are there any experiments on fertilization and/or planting patterns for the intercropping systems in progress at ICRISAT?

Willey:

We give a basal phosphate application of about 40 kg P_2O_5/ha i.e., what would be a good dressing for sole sorghum. We then top dress nitrogen only to the sorghum rows. In a sense, therefore we do not fertilize the pigeonpea. We may find that in the long term, high fertilizer levels will be required to maintain the higher yields from intercropping.

De:

We know little about the nutrient requirements of crops growing in association. I think this is an area where considerable work needs to be done on how best we can fertilize the component crops in intercropping.

Kurien:

The seasonal and regional variation in pigeonpea-producing areas affect the milling behavior, and the content of calcium and other divalents affects the cooking quality. Therefore proper care should be taken to assess the milling and cooking qualities of pigeonpea grown in kharif, in rabi, and on lime-rich soil.

Pandya:

Extra early varieties of pigeonpea such as UPAS-120 have opened new scope for the pigeonpea-wheat rotation in the Haryana and Rajastan irrigation command areas. But farmers may be finding it difficult to obtain pure seed of these varieties, free of contamination from late varieties. Breeders and seed producers should ensure that the genetic purity of the seed supplied is maintained, otherwise the advantage of early cultivars is lost.

U. P. Singh:

I am interested to know why wilt of pigeonpea is reduced when intercrdpped with sorghum. I think sorghum might produce some toxic substances in its root exudates.

Kannaiyan:

Less wilt in the sorghum/pigeonpea intercrop than in sole pigeonpea is a result of reduced *Fusarium* population: this in turn might be due to the effect of substances such as hydrocyanic acid, secreted by sorghum roots, on *Fusarium* propagules.

Hiremath:

Our survey in Karnataka has shown more sterility mosaic disease in pigeonpea when it was intercropped with sorghum or bajra. Do you have any experience in this regard?

Willey:

We have had some indication that this may happen, but I cannot offer any suggestions why. As I said in my talk, intercropping situations are very complex, and although there are some examples of better disease control, there are also examples of worse disease incidence.

Green:

The speakers have been cautious in presenting their reports of progress with nontraditional production methods. In fact, the Bihar farmers have taken Dr. Roy Sharma's rabi planting away from him; in Rajasthan, the farmers have expanded irrigated pigeonpea production very rapidly; and in Western Uttar Pradesh the May planting of T-21 has also spread rapidly. The farmers are not cautious about accepting viable technology and they will be the final judges of the value of a technology.

Byth:

To what extent can the lower yield and lower dry matter (wood) production from June sowing — versus April sowings — be compensated by the use of higher plant densities? What are the actual densities used for the two dates and do you believe they were anywhere near optimum?

Panwar:

Earlier experiments at Kanpur have shown that 60 cm x 20 cm spacing (about 83 000 plants/ha) is optimum; this density was used in the experiment for June-end planting, with one row of urd intercropped between rows. In the April-planted crop, 90 cm x 30 cm spacing (37 000 plants/ha) was used, intercropped with three rows of mung, keeping in view the growth habit in early planting. The optimum density for April planting needs further investigation. I feel it might be lower than what we tried in this experiment. However, there is not much scope for compensating the loss in dry matter and grain yield by increasing plant population densities in June-planted pigeonpea in the central parts of Uttar Pradesh, where the experiment was conducted.

Samolo:

What is the water requirement for growing pigeonpea when it is sown in April? If water is available, why don't the farmers take up vegetable cultivation instead of pigeonpea?

Panwar:

April-planted pigeonpea intercropped with summer mung will need three to four irrigations. This requirement does notdifferfrom that of a sole mung crop. If the farmer wants to, he can grow vegetables as intercrops in pigeonpea; during summer, this should be quite successful.

Gupta:

Spraying operations are difficult in April-planted pigeonpea because of excessive vegetative growth and height. Should we look for dwarf cultivars for April planting?

Panwar:

Yes; cultivars that do not make too much growth and can be harvested by the middle of November will definitely be useful for April planting. However, for pigeonpea T-21 in this system, topping (25%) in the first fortnight of August has improved seed yield significantly and reduced plant height for spraying operations.

Session 2

Environmental Adaptation and International Testing

Chairman: A. R. Sheldrake

Rapporteurs: K. C. Jain
S. C. Gupta

International Adaptation of Pigeonpeas

D. Sharma, L. J. Reddy, J. M. Green, and K. C. Jain*

Abstract

Pigeonpea (Cajanus cajan [*L.*] *Millsp.*) *has a wide adaptability to different climates and soils and is cultivated in most tropical and subtropical environments. India, Kenya, Uganda, Puerto Rico, the Dominican Republic, and Burma are the major pigeon pea-producing countries. However, pigeonpea has mainly evolved in India as an agricultural crop of rainfed drylands.*

To obtain information on the adaptation of varieties in different maturity groups and to identify the major constraints to the production of this crop under different climatic and edaphic factors, an international adaptation trial and several observation nurseries and yield trials of early-, medium-, and late-maturity types and vegetable-type pigeonpea international trials were conducted in several countries in different years. The results from these trials and nurseries are presented in this paper. Our tests in India have indicated that each maturity group has its specific area of adaptation and the results from the international tests reported here tend to support this observation. The early-maturity types are better suited to low-rainfall areas and soils with poor moisture retention. On the other hand, late-maturity cultivars can tolerate adverse conditions such as periodical moisture stress, waterlogging, and mild frost, and they are adapted to such environments better than early and medium types.

The recent discovery of photoperiod-insensitive types has opened up a vista for developing new production systems and for exploring the possibility of extending pigeonpea cultivation to subtropical and temperate regions where temperatures are favorable.

Pigeonpea (*Cajanus cajan* | L.) Millsp.) grows well in tropical and subtropical environments extending between 30°N and 30°S latitude. However, as an agricultural crop of rainfed drylands, it has mainly evolved in India, where over 90% of the world hectarage is seeded. Besides India, Uganda and Kenya in Africa; the West Indies, Puerto Rico, and the Dominican Republic in the Caribbean region; and Burma in Asia are the major pigeonpea-producing countries. Generally, pigeonpea has been introduced into most of the tropical and subtropical countries to which people of Indian origin have migrated. FAO crop production statistics are available only up to 1975, and the reported production of 1.96 million metric tons (tonnes) (Table 1) appears to be an underestimate, since it does not include production figures from some important pigeonpea-growing countries such as Kenya, which has about 115 000 ha under pigeonpea.

Moreover, production from field boundaries, home gardens, and other "fill-in" situations where pigeonpea is often grown is difficult to estimate, although it could be substantial in terms of augmenting the food supply of the small farmers of the tropics. Due to the low input requirement of pigeonpea and its capacity to produce relatively more than most other crops on a limited residual moisture supply, the crop is receiving attention in the rainfed agriculture of some 50 countries (Fig. 1).

In India, evolution of the crop in different agroecological regions and different cropping systems has resulted in numerous locally adapted types (landraces) suited to specific soil-moisture conditions and temperatures. The

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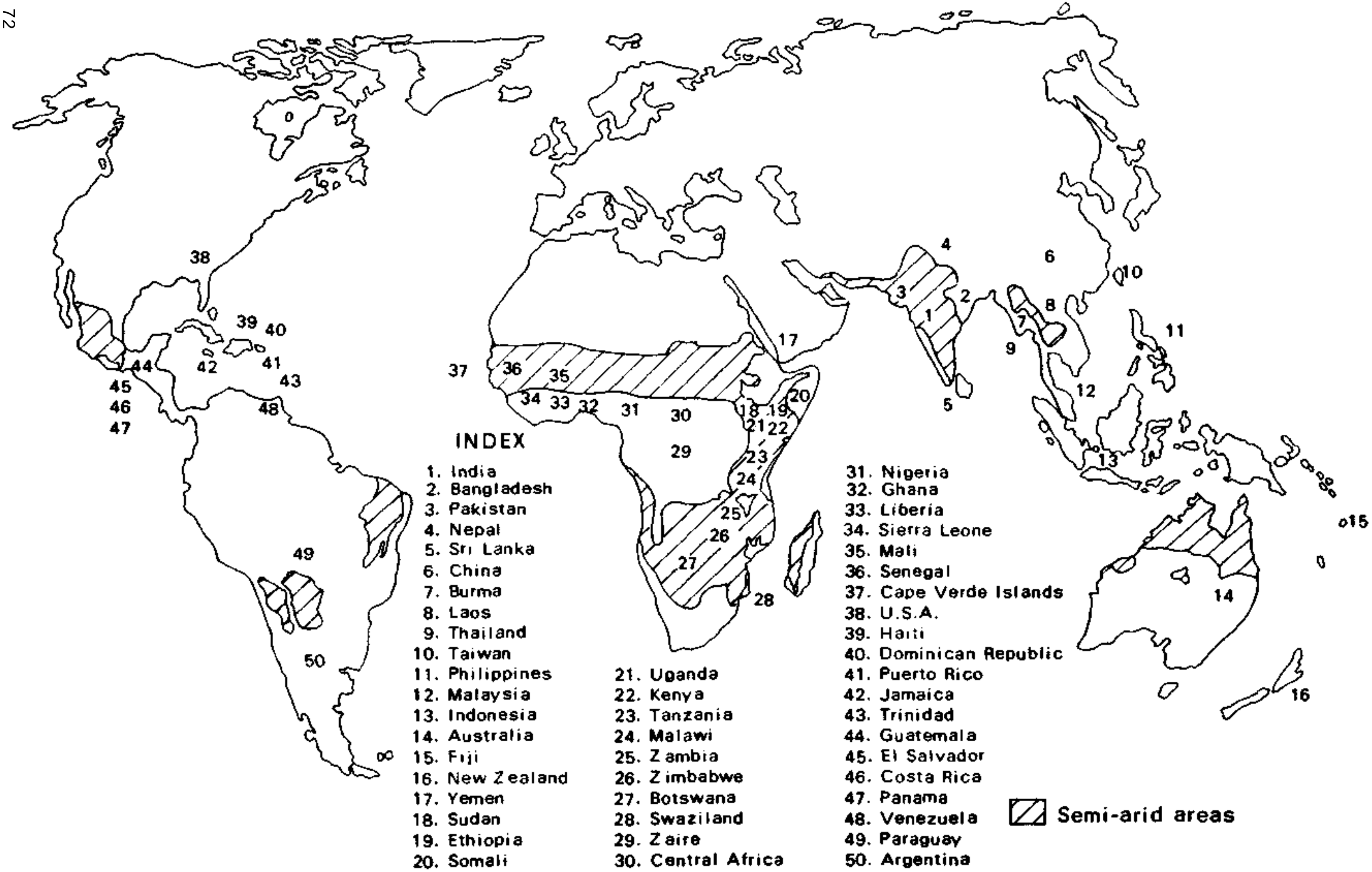

Figure 1. Countries where pigeonpea is grown.

Table 1. Pigeonpea production statistics, 1975.

Country	Total pigeonpea area (000 ha)	Pigeonpea area % arable	Yield (kg/ha)	Pigeonpea production (000 tonnes)	Production (kg/capita)
World	2803[a]	0.20	699	1960	0.49
Malawi	35	1.55	570	20	4.07
Tanzania	20	0.40	500	10	0.65
Uganda	99	2.54	406	40	3.52
Kenya	115[b]	7.28			
Dominican Republic	13	2.02	2194	29	5.67
Haiti	7	1.32	538	4	0.88
Panama	2	0.45	749	1	0.60
Puerto Rico	6	7.06	742	4	1.38
Trinidad, etc.	2	2.86	1667	3	2.97
Venezuela	9	0.19	449	4	0.33
Bangladesh	3	0.03	724	2	0.03
Burma	68	0.68	351	24	0.77
Pakistan	1	0.01	623	1	0.01
India	2540	1.56	716	1818	2.96

Source: FAO production yearbook (1975), vol. 29, except Kenya.
a. Does not include Kenya figures.
6. Area under pigeonpea during 1974-75 in Kenya (Source: Statistical Abstract, Central Bureau of Statistics, Ministry of Economic Planning and Community Affairs, Kenya).

Table 2. Variability for various morphological traits in pigeonpea germplasm collections evaluated at ICRISAT.

		Range for				No. of lines resistant to		
Maturity classification	No. of accessions	No. of countries represented	Plant height (cm)	Seeds/ pod	100-seed wt (g)	Sterility mosaic virus	Wilt	Stem blight
Early[a] (less than 150 days)	237	8	51-250	2.3-4.9	5.2-14.5	17		7
Medium (160 to 180 days)	1235	17	66-325	2.3-5.6	4.7-17.3	53	4	21
Late (above 180 days)	4866	27	70-320	2.2-7.6	4.0-22.2	436	25	94

a. Days to maturity at Hyderabad (17°N).

landraces available in the *country* provide a wide range of variability, particularly for days to maturity, plant type, seed size, number of seeds per pod, and resistance to diseases. ICRISAT has a germplasm collection of 8731 lines from 31 countries, which covers a wide range of variability from different regions (Table 2).

The dominant feature of adaptation has been the identification of pigeonpea types with appropriate maturity durations. For example, since late-maturity types provide enough scope for recoupment and regeneration after adverse conditions such as soil moisture stress, waterlogging, and mild frost, comparatively late types are preferred under the uncertain crop-growing conditions of rainfed subsistence farming. On the other hand, short-duration types are confined to low-rainfall areas that have soils with poor moisture retention, such as Alfisols. The maturity types available range from 120 to 280 days and the appropriate type can be easily selected to exploit fully a given crop season at different latitudes. Broad maturity classification of early (up to 150 days), medium (150 to 180 days), and late (over 180 days) is in vogue in India. However, this classification is of little value in the international context, since pigeonpea is a quantitative short-day plant (critical daylength: 13 hours) and lines within a maturity class vary widely in time taken from planting to maturity, depending on the planting time and the latitude and altitude of a location (Table 3). It is difficult to predict even the gross approximation of crop duration of a particular type when grown outside India based on observation of June-July plantings in India. Work at ICRISAT shows that there are at least four major photoperiod-response groups and that the maturity range of different types can be classified into ten groups (Table 4).

Table 3. Days to 50% flowering in July plantings of the VPPIT-2 entries at Hyderabad (India), Puerto Rico, and Kenya.

Pedigree	Hyderabad (India)	Puerto Rico	Kenya
ICPL-37	97	116	66
ICPL-39	101	133	67
ICPL-36	103	110	67
ICPL-40	109	133	61
ICPL-38	113	92	66
ICPL-35	117	84	68
ICP-6997	125	107	65
ICP-7035	136	96	61
HY-3C	137	86	64
ICPL-41	138	116	68
Range	41 days	49 days	7 days

International Adaptation Trial and Nurseries

An International Pigeonpea Adaptation Trial was initiated by ICRISAT in 1974-75 to provide information on the response of different maturity types and their adaptation in tropical countries covering a wide range of latitudes, planting times, rainfall patterns, soil types, and disease and pest complexes. The objectives of the trial, briefly, were to:

- obtain information on the adaptation of varieties in different maturity groups;
- observe the genotype x environment interaction with particular reference to maturity and yield;
- identify for each country the maturity and plant types needed for its particular cropping systems and consumer preferences;
- provide pigeonpea breeders an opportunity to observe a range of types at their own locations; and
- identify disease and insect problems of a particular region and the reaction of different genotypes to them.

Starting in 1974, trial material of 45 entries — representing 15 each in the early, medium, and late groups — was sent to 19

Table 4. Maturity classification of pigeonpea types at ICRISAT Canter, Hyderabad (17°N).

Group	Days to 50% flowering	Reference cultivar	
0	Upto 60 days	ICPL-81	Photoperiod-insensitive
I	61- 70 days	Prabhat, Pant A-2	Extra early
II	71- 80 days	UPAS-120	
III	81- 90 days	Pusa Ageti, T-21	Early
IV	91-100 days	ICP-6, Baigani	
V	101-110 days	No. 148, BDN-1	Medium
VI	111-130 days	ICP-1, ICP-6997, ST-1, C-11	
VII	131-140 days	HY-3C, ICP-7035	Late
VIII	141-160 days	ICP-7065, ICP-7086	
IX	Above 160 days	NP (WR)-15, Gwalior-3, NP-69	

locations in 18 countries. Characteristics of some of these locations are given in Table 5 and of the entries tested in Table 6.

Some cooperators conducted replicated tests of the entire set, while others planted an unreplicated observation nursery for either the entire set or a part of it. The data furnished for the replicated tests suffered from gaps in information on plant stand, days to flowering, and yield, and the reports from different locations were not uniform. Therefore statistical analysis on the basis of multilocation observations was not feasible. Nevertheless, the observations, though fragmentary, were valuable in meeting the major objectives set forth for the trial.

In addition to the international adaptation trial, several observation nurseries and yield trials of early-, medium-, and late-maturity types and vegetable-type pigeonpea international trials (VPPIT 1 and 2) were sent to different countries. Information obtained both from the nurseries and from the trials is discussed below.

Performance and Utility of Types in Different Regions

West African Region

Pigeonpea yield trials and/or observation nurseries were grown in Nigeria, Liberia, Mali, Senegal, and the Cape Verde Islands. In the West African region the medium- and late-maturity cuitivars generally performed better than the early types. The early cuitivars suffered from pod-borer damage, which the other two types escaped.

During 1978, a trial with 16 cuitivars and germplasm selections of early to late maturity was conducted in Nigeria. No disease of consequence was observed but pests were a major problem. Two Coleopteran pests and five Hemipteran pests were observed to cause considerable damage to the flowers and pods (Table 7). Under unsprayed conditions ICP-7118 (C-11) gave the best yields. However, in trials conducted by IITA at Kadawa, Nigeria, a yield of 4083 kg/ha was reported for the cultivar Cita-4 (3D-8104) grown under a full pesticide umbrella (Nangju et al. 1976).[1]

In Liberia, the early-maturity cuitivars Baigani and UPAS-120, the medium-maturity cuitivars ST-1, BDN-1, C-11, and HY-4, and the late-maturity cuitivars AS-20 and PS-41 were found to be promising.

In Mali, 25 early to late cuitivars were tested. The late ones gave higher yields than the early ones. Five cuitivars flowering in 80 *to* 114 days yielded little more than 1000 kg/ha, and ICP-7222 gave the highest yield of 1700 kg/ha. The early types suffered badly from pod-borer damage, while those flowering at the end of the rainy season largely escaped borer damage.

In Senegal, two trials were conducted, one of ten medium-maturity entries at Sefa and another of eight early-type entries at Nioro du Rip. The trials were planted during July 1978, in a randomized block design with four replications.

Yields of medium types ranged from 903 kg/ha to 2207 kg/ha. ICP-6997 gave the highest yield, closely followed by C-11 and No. 148. The two vegetable types, ICP-7119 (HY-3C) and ICP-7035, gave lower yields than the grain types.

Early-maturity types had much lower yield levels than medium ones; the cultivar DL-74-1 gave the highest yield of 1165 kg/ha.

On the Cape Verde islands, 15 cuitivars and germplasm selections representing early to *late* maturity were planted at the S. Jorge Station during 1978. The early and medium cuitivars were attacked by two pod borers, *Heliothis armigera* and *Etiella zinckenella,* while the late varieties escaped damage. ICP-7035 gave the best yield, followed by ICP-7118 (C-11) and HY-3C. Large-scale introduction of ICP-7035 and HY-3C has been undertaken to allow extensive trials and demonstrations on farmers' fields.

East African Region

Uganda, Kenya, Malawi, Zambia, Tanzania, and Ethiopia are the most important pigeonpea-growing countries in the East African region. ICRISAT trials and/or nurseries were grown only in Zambia, Kenya, and Tanzania.

According to the Central Bureau of Statistics

1. O. Nangju, K. O. Rachie, T. P. Singh, and M. A. Akinpelu. Preliminary results of pigeonpea uniform cultivar trial. Grain Legume Improvement Program, IITA, Ibadan, Nigeria. Personal communication.

Table 5. Characteristics of some of the locations selected for the International Pigeonpea Adaptation Trial, 1975–76.

Country	Location	Cooperating scientist	Latitude	Altitude (m)	Rainfall (cm)	Soil	Time of sowing	Major diseases	Major insect pests
Australia	Redland Bay	E. S. Wallis	27°33'S	3	143	Krasnozem pH 5–6	Nov–Dec		Pod borers
Dominican Republic	San Cristobal	Juan Diaz Gomez	18°25'N	40	196	Alluvial pH 7.6	Apr–May	Virus Myco plasma	
Nigeria	IITA, Ibadan	K. O. Rachie	7°34'N	198	127	Sandy loam having gravel layer pH 6.0–6.5		Fusarium wilt	*Heliothis*
Puerto Rico	Isabela	Raul Abrams	18°28'N	117	164	Coto clay Oxisol	Jan–Feb	*Phoma*, anthracnose	*Heliothis*
Sri Lanka	Mahallu-ppallama	Vignarayah	8°5'N	138	147	Reddish brown red Latosols pH 5.7–7.5	Oct		
Tanzania	Dar-es-Salaam	John Monyo	6°50'S	526	600	Sandy clay pH 5.5–7.0	Dec	Fusarium wilt	
Trinidad (West Indies)	St. Augustine	R. Ariyanayagam	10°38'N		173		May–June Dec–Jan	Rust canker	Pod borers
Zambia	Sesheke	A. Sarmezey	17°30'S	900–1200	70	Light, fairly leached sandy pH 5.5	Early Dec	No data	No data
Zambia	Kaoma	A. Sarmezey	14°45'S	900–1200	96	pH 5.5	Early Dec	No data	No data
Zambia	Magoye	A. Sarmezey	30°S	900–1200	79	Medium heavy loam	Early Dec	No data	No data
Philippines	Los Banos	R. M. Lantican	14°10'N	50	155	Clay loam pH 5.0–5.5	Jan	Fusarium wilt	*Maruca testulalis, Etiella zinckenella*
Thailand	Khon Kaen	T. Charoenwatana	16°26'N	165	119		Dec		Pod borer
Central African Republic	Bangui	E. Lefort	4°23'N	381	156				

Table 6. Characteristics of the varieties included in the Pigeonpea International Adaptation Trial, 1976-76.

ICRISAT No.	Pedigree	Origin	Days to 50% flowering*	Growth habit	100-seed weight*	Seed color[b]
7135	Sri Lanka-15	Sri Lanka	92	Determinate	7.73	0 + B
7141	Sri Lanka-21	Sri Lanka	92	Determinate	9.22	DCB
7144	Sri Lanka-24	Sri Lanka	86	Determinate		RB
28	Pusa Ageti	India	89	Determinate	8.67	B
7172	3D-8126	Nigeria	87	Determinate	7.38	
7220	Prabhat	India	82	Determinate	6.30	B
6972	Pant A-1	India	78	Indeterminate	6.57	RB
6973	Pant A-2	India	70	Indeterminate	6.04	RB
6	2812	India	100	Indeterminate	7.80	B
7179	Pant A-8	India	64	Indeterminate	6.18	B
7219	BS-1	India	69	Indeterminate	7.32	B
26	T-21	India	86	Indeterminate	9.06	RB
7018	Baigani	India	73	Indeterminate	10.48	LCLB
6971	UPAS-120	India	86	Indeterminate	6.38	B
7181	HYB-1	India	53	Indeterminate	8.63	
	ICRISAT-1	India	136	Indeterminate	10.14	B
2624	ST-1	India	126	Indeterminate	8.23	0 + B
7120	No. 148	India	111	Indeterminate	10.80	B
6965	Norman	U.S.A.	99	Indeterminate	5.95	LB
7222	HYB-2	India	92	Indeterminate	11.57	
6997	M.P. collection	India Bangladesh	127	Indeterminate	13.40	B
2817	1183-1	Puerto Rico	141	Indeterminate		
3773	3724	India	111	Indeterminate	8.73	DG + LCB + B
7182	BDN-1	India	70	Indeterminate	10.20	B
7195	PM-1	India	123	Indeterminate	8.38	B
6909	EC-107654	Puerto Rico	124	Determinate	16.89	LCDB
6523	2287	India	119	Determinate	11.44	LCB
6914	Code No. 2	Trinidad	119	Determinate	11.86	LCB
6482	2128	India	80	Indeterminate		LCB
6484	2138	India	125	Indeterminate	8.30	LCB
7221	Gwalior-3	India	153	Indeterminate	8.65	B
6443	NP(WR)-15	India	127	Indeterminate	7.81	OB + LC
7218	PDM-1	India		Indeterminate	8.38	B
7198	KWR-1	India	163	Indeterminate	10.07	
1641	T-17	India	163	Indeterminate	9.50	
6344	T-7	India	127	Indeterminate	8.75	O + B
7119	HY-3C	India	144	Indeterminate	19.20	W
6526	2290	India	135	Indeterminate		
6975	Brazil 465	Brazil	151	Indeterminate	11.57	RB
4779	NP-69	India	171	Indeterminate	13.80	B
7035	Bheda Ghat Coll.	India	147	Indeterminate	22.20	DBRS

Continued

Table 6. *Continued*

ICRISAT No.	Pedigree	Origin	Days to 50% flowering[a]	Growth habit	100-seed weight[a]	Seed color[b]
7065	M.P. Collection	India	162	Indeterminate	7.70	B
4711	EC-100467	India	155	Indeterminate	9.61	O + B
7086	M.P. collection	India	169	Indeterminate	16.40	W
2629	Grenada	Grenada	99	Indeterminate		

a. Based on the observations at ICRISAT Center, Hyderabad.
b. O + B = Orange + brown
DCB = Dark cream brown
RB - Red brown
B = Brown
LCLB = Light cream light brown
LB = Light brown
DG = Dark green
LCB - Light cream brown
LCDB = Light cream dark brown
OB = Orange brown
LG = Light green
W = White
DBRS = Dark brown with red streaks

Table 7. Insect pasts found in the pigeonpea trials at Nsukka, Nigeria. 1978-79 season.

Name of insect	Plant parts attacked
Order: Coleoptera	
Mylabris seminigra	Flower buds
Mylabris farquharsoni	Flower buds
Order: Hemiptera	
Acanthomia tomentosicollis	Pods
Nerjara viridula	Pods
Acrosternum acutum	Pods
Anoplocnemis curvipes	Pods
Taeniothrips sjostedti	Flowers

(Anonymous 1976), Kenya grows around 115 000 ha of pigeonpeas and is next only to India in pigeonpea hectarage. The traditional tall late-maturity types in Kenya are highly adapted and are well suited to the high altitudes and the bimodal rainfall pattern found in Kenya. The major constraints to growing early types in this location are the pod borer, *Heliothis armigera,* and the podfly, *Melanagromyza obtusa.* Diseases are a major problem in the traditional late-maturity types. There is a high incidence of Fusarium wilt, with 10 to 15% affected plants found in all the pigeonpea-growing districts of Kenya. In the high-rainfall areas, a leaf spot disease (*Mycovellosiella cajani*) causes severe yield losses ranging from 22 to 69% (Onim 1975) and in the dry areas, powdery mildew (*Leveillula taurica*) is a major disease.

In Kenya, the pigeonpea crop is grown to provide not only dry grain but also canned green peas for export. Two vegetable-type pigeonpea international trials (VPPIT 1 and 2) were conducted in Kenya. The results of these tests, reported separately at this workshop, indicate that several ICRISAT entries in VPPIT-1 were superior to one of the local checks in yield; in grain size most of the lines were superior to both the local checks. That is, the entries in VPPIT-2 were on a par with the best local check for yield but had the added advantage of having large seed size. Many ICRISAT entries from these two trials are being used as parents in the Kenyan national breeding program. In the pigeonpea uniform cultivar trial conducted during 1975 by IITA at Mombasa, Kenya, the highest grain yield (3061 kg/ha) was reported for an early semidwarf pigeonpea type, Cita-1, developed by IITA scientists (Nangju et al. 1976, personal communication).

Three separate pigeonpea yield tests for early, medium, and late groups were constituted out of the entries of the international adaptation trial and were planted during December 1975 at Mufulira, Zambia. In addition, a vegetable pigeonpea international trial (VPPIT-2) was conducted during 1977.

Medium-maturity cultivars in general gave the highest mean yields. The cultivars ICP-7035 (5322 kg/ha), HY-3C (4961 kg/ha), and ICPL-41 (4383 kg/ha) included in VPPIT-2 were the most promising. In Zambia, Dr. Sarmezey has multiplied HY-3C and Baigani for distribution to farmers and has initiated selection in the F_3 bulk population of the crosses HY-3C x ICP-7035 and ICP-7035 x Baigani supplied by ICRISAT. These selections are being made to recover the yield potential of ICP-7035 and the white seed color of HY-3C and Baigani.

In Tanzania, 45 early to late-duration cultivars were tested, along with three local (Morogoro) selections and three exotic lines. The medium and late cultivars gave higher yields than the early cultivars. Mukta and PM-1 (ICP-7195) gave higher yields than the local Morogoro selections. While *Heliothis armigera* was the major pest on early and medium-duration cultivars, *Acanthomia tomentosicollis* was found to cause considerable damage to the medium and late cultivars, and powdery mildew (*Leveillula taurica* Lev. Arm.) was noticed on all the lines.

North Central America

In this region, pigeonpeas are grown in the Dominican Republic, Haiti, Panama, Puerto Rico, and Trinidad, mostly for canning of green peas. The highest average pigeonpea yields (2194 kg/ha) in the world are reported for the Dominican Republic (Anonymous 1975).

In Puerto Rico, only 15 out of 45 early to late-maturity entries of the international adaptation trial were tested during 1976. In addition, one international vegetable-type pigeonpea nursery in 1977 and two international vegetable pigeonpea tests of early (VPPIT-1) and medium (VPPIT-2) cultivars were conducted in 1978. In the first test of 15 entries, ICP-7035 gave the highest yield (1395 kg/ha). Inthe vegetable-type nursery, 38 ICRISAT entries along with two local checks, 2B-Bushy and Kaki, were tested, and the ICRISAT entries, in spite of maturing 24 to 55 days earlier, were on par with the local checks for yield. In the VPPIT-1, most of the lines outyielded the local checks, while in VPPIT-2, ICP-6997 outyielded the best local check and was earlier maturing.

At Panama, in the International Vegetable Nursery conducted during 1977, the ICRISAT entries gave better green pea yields (4740 to 5265 kg/ha) than the local checks (4702 to 5122 kg/ha), in spite of being earlier than the checks by 6 to 152 days.

Indian Subcontinent

Apart from India, pigeonpeas are grown to some extent in Burma, Pakistan, Bangladesh, Nepal, and Sri Lanka. Since work conducted in India is being reported separately at this workshop, we have not dealt with this aspect here.

In the international adaptation trial in Burma, early and medium-duration cultivars HPA-1, PM-1, and ICP-6997 gave 2200, 2082, and 2073 kg/ha respectively. Large-scale seed multiplication of HPA-1 is being carried out by FAO scientists to provide seed for distribution to farmers.

in Pakistan, 20 early to late cultivars were yield-tested at Sham-ki-Bhattian, Lahore, during 1977, and an advanced early lines test consisting of 20 entries was conducted during 1978 at Lahore. A medium-duration cultivar gavethe highestyield (1639 kg/ha) during 1977, while in the early cultivar test during 1978, advanced lines yielded up to 2320 kg/ha. These lines can be easily harvested by the end of November to facilitate sowing the normal wheat crop.

In Nepal, replicated yield tests of 12 cultivars and germplasm selections were conducted in a randomized block design with four replications at four locations — Hardinath, Nepal-gunj, Sarlahi, and Parwanipur. The highest mean yields across all the four locations were recorded for two late maturity cultivars, Gwalior-3 (1901 kg/ha) and ICP-7065(1646 kg/ha). A yield of 4168 kg/ha, the highest for the country, was recorded for Gwalior-3 at Birgunj. A low incidence of podfly, *Melanagromyza obtusa,* and wilt was observed in Nepal.

In Bangladesh, ten medium- to late-duration cultivars were tested as a *rabi* (postrainy season) crop after the harvest of the rice crop in October. The results were promising, with C-11 giving the best yield (1511 kg/ha).

In Sri Lanka, three yield tests were conducted of early, medium, and late groups, consisting of 15 entries each. No differences in yield levels were observed between early, medium, and late types. Early types such as Prabhat escaped pod-borer damage, which was heaviest on the medium and late types. Late types have been grown in the traditional agriculture on the island, but early-maturity types are being tried in their farming systems research aimed at increasing cropping intensity.

Far East

In the Philippines, 40 early to late-maturity cultivars weretested. Early cultivars gave better yields than medium and late ones. The latter types were caught in heavy rains, which started in May and continued until October. It appears that cultivars that take 4 months to maturity when planted in January are best suited to this test location. Pod borers *Maruca testulalis* and *Etiella zinckenella,* are major pests.

In Taiwan, ten cultivars representing early to medium maturity were tested at Taipei during 1978. The local late cultivars ranging in maturity from 256 to 302 days gave better yields (1117 to 2167 kg/ha) than the early and medium cultivars supplied by ICRISAT.

In Malaysia, a trial of 16 cultivars and germplasm selections representing early to late-maturity types was conducted. Pod *borers* were the major problem due to the high humidity and moderate temperatures throughout the year. Because of the continuous high soil moisture found under Malaysian conditions, ripening of pods at different times could be a problem when using pigeonpea for dry grain. However, possibilities exist for using the crop for green vegetable consumption where the green pods could be picked as they reached the appropriate stage of maturity.

Oceania

In Australia, Akinola and Whiteman (1972) have classified the University of Queensland *Cajanus* collections and identified promising types. Although production levels of dry seed for some of these, particularly UQ-50, were good (up to 7000 kg/ha/year from hand-harvested experimental plots with up to three pickings) in particular environments, serious limitations to production in the potential grain-growing areas were identified (Wallis et al. 1979). The major limitations to the widespread production of UQ-50 were:

- frost susceptibility,
- a relatively long vegetative phase,
- a requirement for a high level of management skills by farmers in manipulating the planting dates and plant densities for recovering maximum yields, and
- *Heliothis* damage, particularly in plantings made before the longest day.

To circumvent some of these problems, the workers at the University of Queensland are emphasizing the identification and development of early-maturity, photoperiod-insensitive cultivars that are amenable to machine harvesting. To this end, a set of 15 ICRISAT early cultivars and three IARI (New Delhi, India) cultivars, along with two local checks, UQ-50 and UQ-11, were tested. UPAS-120 and ICP-6 gave yields of 3160 kg/ha and 3150 kg/ha respectively, as compared with 2760 kg/ha for the best local check cultivar UQ-50.

Recently, a photoperiod-insensitive early line has been developed from an off-type plant identified in the ICRISAT accession ICP-7179 (Pant A-8) by UQ scientists. Dry seed yields of up to 2600 kg/ha were harvested for this new insensitive line by manipulating the planting time and plant density (Wallis et al. 1979).

A trial consisting of 12 ICRISAT entries, three IITA cultivars, and seven local cultivars was conducted in Fiji. Late-maturity cultivars gave better yields than the early ones. ICP-7065 outyielded the local checks and the IITA cultivars in the test.

Adaptation to New Unconventional Areas

Isolation of a photoperiod-insensitive line at the University of Queensland, Australia, and a number of similar lines at the ICRISAT Center, Hyderabad, opens up new vistas for extending the adaptation of the crop to subtropical and temperate regions, where pigeonpeas can be successfully grown under irrigation during the short summer season in spite of long days. Also, these lines would be very useful in allowing the crop to be used in systems where only short-duration pigeonpeas of 110 to 120 days duration fit. The Pulse Research Directorate at Kanpur, India, is evaluating the potential of these lines for irrigated agriculture. They are trying these lines in February or early March plantings, after the sugarcane crop has been harvested, or as a summer crop after wheat This material requires thorough evaluation and extensive testing in new areas to develop the information necessary for working out a profitable production system.

Recently in India, extra early pigeonpeas of 125 to 130 days have received considerable attention in the northwestern regions of Rajasthan (canal irrigated area, Ganganagar), Haryana, and Punjab, as part of a pigeonpea-wheat rotation. Under these conditions it has not been difficult to obtain yields of 2000 kg/ha. Such new areas are likely to play an important role in increasing pigeonpea production in India, where the production level of this crop has been static for several decades.

Conclusions

Pigeonpea has a wide adaptability to different climates and soils, and is cultivated to some extent in most tropical and subtropical environments. The exceptions are areas that are excessively wetor that experience severe frost. This crop can tolerate higher temperatures than other legume crops such as chickpea, lentils, and peas.

Identification of an appropriate maturity duration type for a given location has been the dominant feature of adaptation for this crop. The early-maturity types are better suited for low-rainfall areas and for soils with poor moisture retention. These cultivars suffer heavy damage from pests and diseases under high rainfall conditions because of the extended humid and cloudy weather. Late-maturity cultivars can tolerate adverse growing conditions — such as periodic moisture stress, waterlogging, and mild frost — better than the early and medium-duration types. Our tests in India have indicated that each maturity group has its specific area of adaptation. The results from the international tests reported in this paper tend to support this observation.

By and large, pigeonpeas have been grown either as annuals for intercropping during the main rainy season or as perennials on field boundaries and home gardens. There is a tremendous potential for growi ng pigeonpeas as a postrainy crop after the main crops such as paddy have been harvested, when favorable photoperiod and temperature conditions exist. In areas where temperatures are moderately high and daylengths are short, pigeonpeas can compete favorably with many of the traditional rabi crops grown under receding soil moisture conditions.

With the introduction of early and extra early photoperiod-insensitive types, new systems of pigeonpea production — such as summer planting with irrigation and irrigated production in dry areas with marginal soils at any latitude — can be explored, provided temperatures are favorable.

References

AKINOLA, J. O., and WHITEMAN, P. C. 1972. A numerical classification of *Cajanus cajan* (L.) Millsp. accessions based on morphological and agronomic attributes. Australian Journal of Agricultural Research 23: 995-1005.

ANONYMOUS. 1975. FAO production year book, 1975, vol. 29. Rome, Italy: FAO.

ANONYMOUS. 1976. Statistical abstracts. Central Bureau of Statistics, Ministry of Economic Planning and Community Affairs, Kenya.

ONIM, J. F. M. 1975. Pigeonpea improvement in East Africa. Presented at the Pigeonpea Breeders Meeting. ICRISAT, 16-17 December 1975, Hyderabad, India.

WALLIS, E. S., WHITEMAN, P. C., and BYTH, D. E. 1979. Pigeonpea *(Cajanus cajan* [L] Millsp.) production systems in Australia. Presented at the Regional Workshop on Tropical Grain Legumes, University of [the West Indies, 18-22 June 1979, St. Augustine, Trinidad.

Varietal Adaptation to Production Systems

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Abstract

Pigeonpea is the major kharif pulse of India. Recently, the Indian program has identified several new niches in which this crop could find a place. This paper analyzes the constraints faced in tailoring varieties to production systems, traditional and recent. Traditionally, pigeonpea is a crop occupying the land nearly the whole year, generally as a component of an intercropping system, although there is considerable variation in the practices adopted. Breeding for intercropping situations has, however, been limited. The results of recent studies on evaluating genotypes for their suitability for intercrop conditions have been reviewed. An interesting aspect of the studies has been the differential response of genotypes to cropping systems. Other cropping systems that have become feasible in recent times involve shifting pigeonpea to new niches in space and or time. The performance of different genotypes in the new niches has given enough evidence of the exciting possibilities open to the breeder to tailor this crop to various climatic and agroecological requirements.

Pigeonpea is grown in many situations in India. Traditionally in north and central India, which contribute most to pigeonpea production, it is thought of as a crop occupying the land for over 9 months. As such, and because of the low returns, it is generally considered suitable only for growing as an intercrop or mixed crop with short-duration, high-return crops such as sorghum or pearl millet. This practice aims to exploit the land, moisture, and sunlight resources optimally. Analysis of resource use has confirmed the superiority of sorghum/pigeonpea intercropping compared with either grown as a pure crop. Willey and Natarajan (1980) have shown that light interception by the intercrop throughout the growth period is higher, at 32 kcal/cm^2, compared with 30 kcal/cm^2 by the sole pigeonpea and 19.4 kcal/cm^2 by the pure sorghum. Intercropping is also more efficient in terms of conversion of the intercepted light energy into dry matter. Total evapotranspiration is little affected by cropping pattern and hence there is no extra water consumption in intercropping; 61% of this is transpired as against 68% in the sole sorghum, the more efficient component. There is little difference, therefore, in water utilization by the two cropping systems.

While a large percentage of the area under pigeonpea is indeed grown under the situation described above, there is considerable variation not only in the companion crop but also in the proportions of the companion crop and pigeonpea. Mehta (1970) and Laxman Singh (1980) have listed some of these situations. Laxman Singh and Shrivastava (1976) made an extensive survey of the different cultivation systems in Madhya Pradesh in which pigeonpea finds a place and attempted to characterize the landraces found under each of these systems. They were able to define at least nine distinct plant types from over 900 collections, differing in height, spread, adaptation, and other characteristics. Their results are summarized in Table 1. These types, except possibly for the single-culm or soy types, agree fairly closely with the types recorded by Shaw et al. (1933). It is obvious, therefore, that human and natural selection has resulted in the development of plant types suitable for various situations. The great plasticity of the taxon is

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Table 1. Characteristics of iandraces of plgaonpea grown undar different agroacologlcal situations in Madhya Pradash, India.

Type	Duration (days)	Plant type: Height (cm)	Spread (cm)	Habit	Cultivation system
1	180-200	130-160	70-80	Semitall, bush	Mixed with kodo millet, medium-deep soils, over 100 cm rain
2	180-200	200	50	Tall, compact	Sorghum/bajra on medium deep soils, 80 cm rain
3	250 *and* over	*220*	130	Tall, spreading	Sorghum on deep fertile soils
4	130-160	150	70-80	Medium tall, spreading	Sole crop or intercrop with cotton/groundnut, shallow soils, 70 cm rain, or very shallow soils, over 70 cm rain
5	160-180	100	30-40	Short, determinate (Pusa Ageti) type	isolated
6	120-140	90-100	25-30	Almost single culm	Sole cropping in hilly districts
7	180-200	150	50	Medium tall, inflorescence bunched	Mixed with maize, sorghum, kodo millet
8	180-200	130	25	Short, compact	Mixed with maize, sorghum, kodo millet
9	180-250	90	10-15	Short, single culm	Sole crop

Source: Laxman Singh and Shrivastava (1976).

also evident and is particularly interesting from the breeder's point of view.

Breeding for Adaptation to Intercropping with Tall Millets

Efforts to breed types adapted to specific situations have been limited. This is perhaps understandable when we consider the long duration of the crop, the varied composition of the field, and the difficulties in evaluating genotypes in intercropping or mixed-cropping situations. Particularly under rainfed conditions, where substantial fluctuations in environmental conditions are quite common, this can be quite difficult. Another important factor has been that traditional intercropping has been more or less replacement cropping, the population of both crops being less than optimal, a practice more oriented to insuring thefarmer against risk than to increasing production per unit area. Recent studies have shown that it is possible *to* use optimum or near-optimum populations of both components and achieve a land equivalent ratio of 1.6 or 1.7 (Willey and Natarajan 1980; Shelke and Krishnamurthy 1980).

The basic question from the breeder's point of view would be whether genotypic differences in response to intercropping exist in pigeonpea. In the Indian program a few studies have been undertaken on evaluating genotypes in such scientific intercropping situations. The problem has been approached in two ways. First, in some centers of the project the evaluation of late (ACT-3) genotypes and populations in the Indian program is being carried out under intercropped conditions, using the crop and planting system conventional to that area. A second approach has been to compare the ranking of genotypes for yield in sole-crop and intercrop situations.

Table 2 summarizes the performance of

Table 2. Yield and ranking of different pigeonpea genotypes/bulks grown in sole and intercropped situations at Sehore, kharif 1976.

Genotype	Maturity group[a]	Yield (kg/ha) Sole crop[b]	Yield (kg/ha) Inter-crop[b]	Reduction Actual	Reduction % of Sole crop	Rank Sole crop	Rank Inter crop
NP (WR) 15	ACT-3	1353	725	628	46	1	3
Gwalior 3	ACT-3	1222	878	444	28	2	2
C-11	ACT-2	986	659	327	33	4	4
JA-5	ACT-2	766	504	262	34	5	5
No. 148	ACT-2	753	273	480	64	6	7
S-5	EACT-1	283	160	123	44	12	11
Sehore Local	ACT-1	720	387	333	46	7	6
T-21	ACT-1	421	141	280	67	9	12
Pant A-1	EACT-1	256	137	119	47	13	13
NP(WR) 15 X 1258 F_3	ACT-3	1020	935	85	8	3	1
JA-275 x Sharda F_3	ACT-2	538	297	241	45	8	8
JA-275 X P-334	ACT-2	370	270	100	27	10	9
GWL-3 x P-334	ACT-3	365	234	131	36	11	10

Source: Laxman Singh at al. (1978).

a. See Ramanujam and Singh, Session 10, these proceedings, for explanation of maturity groupings.

b. Spacing for pigeonpea 90 cm x 30 cm; intercrop sorghum at 45 cm from pigeonpea. Genotypic and growing conditions significant; interaction nonsignificant.

pigeonpea genotypes of different maturity classes (as well as F_3 bulks of four crosses), grown as a sole crop and intercropped with sorghum (Laxman Singh et al. 1978) in *kharif* (rainy season) 1976. By and large, the ranking has remained the same under both situations. Also, in spite of the pigeonpea population remaining the same, there has been a depression in yield in the intercropped situation, the extent of reduction being a measure of the competition from the growth of sorghum in the early period. Long-duration (ACT-3) genotypes and one F_3 bulk of a cross between two such types have done better under both situations than ACT-2 and ACT-1 types or crosses between them. The one EACT type included in the study has been the poorest in terms of yield, under both sole and intercropped situations. However, the extent of reduction in pigeonpea yield brought about by competition from sorghum varies within a narrow range of 35 to 50% of the yield in the sole-crop situation. The only exceptions are T-21, which has suffered a loss of 67%, and the F_3 bulk of the cross between two late-maturing types—NP (WR) 15 x 1258 —which has suffered a loss of only 8%. The latter has thus given practically equal yields under sole and intercropped conditions. This behavior is particularly interesting and needs to be followed up for confirmation and analysis. It is interesting to note that one of the parents of the F_3 bulk, NP (WR) 15, has itself suffered a 46% reduction under intercropped conditions.

The results (Anonymous 1978) of a similar trial carried out with the ACT-3 set of the All India Program by ICRISAT in the 1977 kharif are shown in Table 3. The companion crop was maize.

In this trial, the pigeonpea genotypes were all of the late-maturity group. Whilea few varieties, including the top yielderK-23, gave more or less the same yield (±1000 kg/ha) under both conditions, others, including NP (WR) 15, gave appreciably lower yields under intercropping. However, of 13 entries, five actually gave a higher yield under intercropping than they did in sole cropping. The increase under intercropping varied from 900 to 1900 kg/ha, or 10 to 25% of theyield under sole cropping. This last group includes genotypes developed several years

Table 3. ACT-3 trial at ICRISAT, Gwalior, using sole-crop and intercrop situations, kharif 1977.

Genotype	Yield (kg/ha) Sole crop	Yield (kg/ha) Inter crop	Reduction due to intercropping Actual	Reduction due to intercropping Percent of sole crop	Rank Sole crop	Rank Inter-crop
NP(WR) 15	850	570	280	32.9	7	11
AS-29	980	900	80	8.2	3	6
PS-43	770	960	-190	-24.7	10	4
PS-65	770	650	120	15.6	10	12
PS-66	640	800	-160	-25.0	13	8
PS-41	730	850	-120	-16.4	12	7
GWL-3	870	960	-90	-10.4	6	3
1234	810	990	-180	-22.2	8	1
1258	770	940	-170	-22.1	9	5
T-7	980	770	210	21.5	3	9
K-16	1000	750	250	25.0	2	10
K-28	880	430	450	51.1	5	14
K-23	1110	1070	40	3.6	1	1

Source: Anonymous (1978).
Genotype, growing system, and interaction significant.

earlier, such as GWL-3 (Madhya Pradesh) as well as genotypes such as 1234, 1258, PS-43, PS-66, and PS-41, developed recently by the scientists at Rajendra Agricultural University, Dholi, Bihar, and the Pusa (Bihar) Regional Station of the Division of Genetics, IARI. The genotypes of the last group are, however, somewhat low-yielding in a sole-crop situation. Perhaps they are poor competitors and could benefit from a higher population than was used in the study.

On the basis of the results (repeated over 3 years) from Sehore, a location representative of the general situation for sorghum-pigeonpea intercropping, one might perhaps be tempted to generalize that evaluation under sole-crop conditions, preferably using high population density, gives a reasonable assessment of the relative productivity of pigeonpea genotypes under intercropping. A similar conclusion has been reached by Francis et al. (1978a, 1978b), who evaluated climbing as well as nonclimbing genotypes of *Phaseolus vulgaris* for suitability for intercropping with maize.

A closer inspection of the data from different centers, however, suggeststhat this may not be the whole story. Table 4 presents the correlation between pigeonpea yields in sole and intercropping situations.

The relationship can be seen to vary from location to location. There is apparently a genotype x cropping system x environment interaction that must be taken into account.

What is perhaps more interesting from the breeding point of view is the behavior of certain genotypes that under intercropping have given yields higher than or almost the same as they have given under sole cropping. Table 5 summarizes the data from four different locations.

Admittedly, more testing may be needed, but these few genotypes may be the ones the breeder should pick out and test more extensively to confirm their behavior. Going only by the existence of a nonsignificant genotype x cropping system evaluation, where a large number of "unresponsive" genotypes are involved, may swamp such nonconfirming genotypes, which may be few in number.

Reaction to Intraspecific and Interspecific Competition

Evaluation under sole-crop conditions must

Table 4. Correlation of sola and Intercropped pigeonpaa yields at four location*.

Location	Main Crop	Correlation: Simple	Correlation: Rank	Pigeonpea types
Sehore	Tall sorghum	+ 0.922**	+0.94**	EACT, ACT-1, ACT-2, ACT-3
Hyderabad	Hybrid maize	-0.13	-0.02	ACT-3
Dholi	Hybrid maize	+ 0.95**	+ 0.83**	ACT-3
Parbhani	Hybrid sorghum	+ 0.306*	+0.166	Fa population

**, * = significant.

Table 5. Yields in sole and intercropped situations of some pigeonpea genotypes at four locations.

Location/ genotype	Pigeonpea yield (kg/ha): Sole crop	Pigeonpea yield (kg/ha): Intercrop	Percent reduction in intercrop[a] over sole crop
Hyderabad		Hybrid maize	
PS-43	770	960	-25
PS-66	640	800	-25
PS-41	730	850	-16
GW-3	870	960	-10
1234	810	990	-22
1258	770	940	-22
Sehore		Tall sorghum	
F_3NP (WR) 15 x 1258	1020	940	+8
Dholi		Hybrid maize	
PS-41	1340	1280	+ 5
Parbhani		Hybrid sorghum	
F_3 population			
No.38	630	840	-33
No. 56-49	630	740	-18
No. 56-50	780	910	-17
No. 220	680	780	-13
No. 56-45	1090	1210	-11
BDN-1	870	880	-2
No. 56-30	1120	1110	+ 1

a. Negative sign indicates higher yield under intercropping.

obviously be *at* optimal population levels and not at the sparse population one normally finds in the traditional intercrop situation. An interesting point that needs consideration, therefore, is the response of pigeonpea genotypes to intraspecific as well as interspecific competition.

An assessment of genotypic response to intraspecific competition can be obtained from an analysis of the data provided by Laxman Singh et al. (1977), who tested three pigeonpea genotypes of differing maturity in different planting patterns. Table 6 gives a reanalysis of the data, adjusting yields for the number of plants per m^2. Both JA-3 and Khargone-3, which have not been developed for intercropping situations, gave reduced yields with increased population per m^2. InNP(WR) 15, which is used widely in intercropping, there is actually an increase, or at least no reduction, in yield with a fivefold increase in population irrespective of whether the plants are hill- or space-planted; even with a tenfold increase in plants per m^2, the adjusted yield is only 25% less. For Khargone-3 this loss is around 40%, and for JA-3 as much as 65%. At a population of 30 plants per m^2, all three genotypes suffer equally.

Data in Table 7 illustrate the effect of an increase in pigeonpea yield when the space available per plant is increased from 675 sq cm to 2700 sq cm by (P) increasing the spacing of pigeonpea from 45 x 15 cm to 90 x 20 cm and (S) by increasing the spacing of pigeonpea further (180 x 60), but planting three rows of sorghum spaced at 45 cm between two pigeonpea rows (Fig. 1).

In respect of plant height and primary branches most genotypes, except Local, respond similarly to both situations. In respect of secondary branches there is in general a decrease in the sorghum intercropped situation (6801 being an exception); in the sole pigeonpea there is an increase. GWL-3, 6826, and Local show increased spread, the increase being appreciably greater in the intercrop than in thesole pigeonpea in thefirst two genotypes. In 6826, this is reflected in an increase in per plant pod number and seed yield, but not in GWL-3. Though no clear patterns emerge, there is enough evidence for differential genotypic response.

With the development of hybrid sorghums, we have dwarf, short-duration genotypes likely to offer less competition to pigeonpea. Also, the hybrids have been selected for their population performance and may exhibit less competition with their neighbors than the conventional types (Donald and Hamblin 1976; Krishnamurthy et al. 1980); it is not at once clear that reduced intraspecific competition should necessarily indicate reduced interspecific competition. Using such a sorghum genotype, CSH-6, planted in paired rows, Tarhalkar and Rao (1980) have examined genotype x density interaction and their role in optimizing the cropping system.

Table 6. Intraspecific competition in three genotypes of pigeonpea of different maturity.

Spacing (cm)	Increase[a] in population/m²	NP (WR) 15 (Late) Actual yield (kg/ha)	Increase[a] in yield over 100 × 100	Yield increase/ Pop. increase	JA-3 (Medium) Actual yield (kg/ha)	Increase[a] in yield over 100 × 100	Yield increase/ Pop. increase	Khargone-2 (Early) Actual yield (kg/ha)	Increase[a] in yield over 100 × 100	Yield increase/ Pop. increase
100 × 100		173			162			111		
20 × 100	5	999	5.4	1.1	647	4.0	0.8	487	4.5	0.9
(5×100) × 100[b]	5	1017	5.5	1.1	642	4.0	0.8	380	3.6	0.7
(10×100) × 100[b]	10	1208	7.5	0.8	522	3.23	0.3	646	5.8	0.6
3.3 × 100	30	1626	9.4	0.3	1114	7.0	0.2	1040	10.0	0.3

Source: Laxman Singh et al. (1977).
a. Increases in population/yield are expressed as the number of times over the relevant parameter at 100 × 100 cm spacing.
b. Hill planting.

Table 7. Effect of Increasing the area available* to pigeonpea on seed yield per plant and some growth characters.

Genotype	Type of comp.	Plant height (cm)	Primary branches	Secondary branches	Spread (cm)	Pods/ plant	Yield/plant (9)
GWL-3	P	-19	+21	+ 1	+ 10	+ 157	+ 42
	S	- 4	+ 24	-2	+21	+ 33	+ 26
6826	P	+23	+ 22	+ 4	+ 9	+ 144	+35
	S	+21	+ 24	-1	+ 17	+ 258	+48
K 6801	P	-20	+ *20*	+6	+ 16	+ 148	+24
	S	-17	+ 7	+ 4	0	+ 36	0
6842	P	- 1	- 4	-3	+ 8	+ 95	+ 9
	S	- 9	+ 5	-1	-10	+ 48	+ 14
Local	P	- 2	+ 19	+3	+37	+ 186	+ 74
	S	+ 5	- 5	-4	+ 15	+ 60	+47

a. From 675 to 2700 cm^2 by (P) increased spacing (90 x 20 cm) of pigeonpea and (S) by further increased spacing (180 x 60 cm) but with three rows of sorghum, 45 cm apart, interplanted (see Fig. 1).
P = Intraspecific competition; S = Interspecific competition.

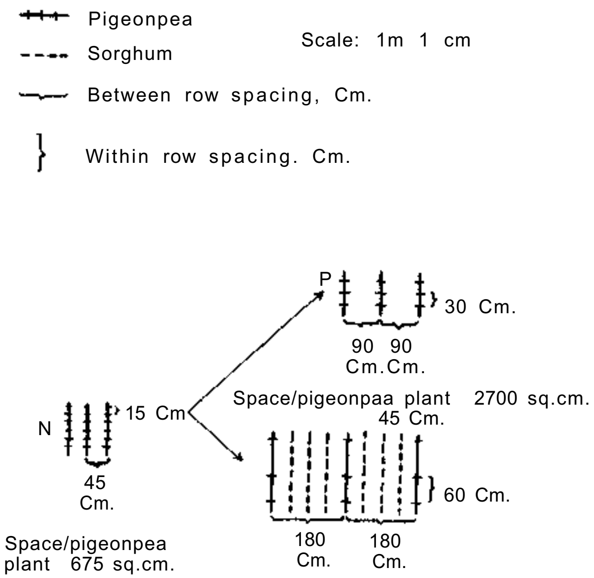

Figure 1. Planting pattern used by Singh et al. (1977: see Table 7).

They found that sorghum yield was little affected by changes in planting patterns, but the highest total and net returns were obtained when the sorghum rows were paired or 60-cm-wide single rows were used and intercropped with pigeonpea. These authors also reported an interesting genotypic difference; when the sorghum was in 60-30 paired rows, HY-2, a medium-duration bushy pigeonpea genotype, suppressed sorghum more than HY-3, a long-duration erect type lacking basal branches. HY-2 also gave poorer yields than HY-3.

The results presented above, taken all together, do suggest that there may be genotype x cropping system interaction; it is also clear that there is a genetic component in the adaptation of pigeonpea to intercropping with sorghum. We would, perhaps, be justified in extrapolating this to include the other tall millet, bajra, with which pigeonpea is also commonly intercropped, and similar crops. There should therefore be scope for developing elite varieties that in intercropping situations could give performances comparable to the sole-crop situation.

Other Intercropping Patterns with Pigeonpea

Sugarcane is another long-duration crop occupying the field for 12 to 18 months. Experiments carried out at the Sugarcane Breeding

Institute at Coimbatore have shown that it is possible to successfully intercrop sugarcane with pigeonpea, using early-maturing varieties such as S-5 and S-8.Distinct differences in the responses of different genotypes to such intercropping, as well as their effect on sugarcane productivity, have been reported (Ramanujam 1973).

Many other intercropping situations involving pigeonpea have been identified by the scientists of the project. In particular, those involving the intercropping of pigeonpea as the dominant crop with shorter duration legumes such as mung bean, urd bean, cowpea, and even soybean, described as "parallel cropping," have proved attractive. The pigeonpea population is maintained at its optimum level and the parallel crop is adjusted in between the pigeonpea rows. In such situations, however, the attempt so far has been to select genotypes of the intercrops to fit into the system rather than to tailor the pigeonpea component. Obviously, however, selection of a suitable genotype of pigeonpea — indeed of both components —that offer the minimum competition to each other when they are grown at their optimum population levels, could prove advantageous.

Shifting Pigeonpea to New Niches in Space

In the recent past, considerable interest has been generated in introducing pigeonpea into new niches in intensively cultivated areas as well as other new niches, new that is, for pigeonpea. These situations have been identified only recently, but some breeding effort has already gone into developing varieties adapted to them. The major emphasis of such breeding programs has been to assess existing cultivars under these new situations and try to develop superior genotypes, keeping in view the agroecological constraints operating in such situations.

The identification of early-maturing varieties of the T-21 category, coupled with the availability of wheat varieties thatdid best when sown as late as the middle of November, stimulated interest in the development of the pigeonpea-wheat rotation in the northern plains of India. Agronomic and varietal evaluation research under such situations revealed the practicability of such a rotation even in Punjab and Haryana, where pigeonpea could not be cultivated in the past because of frost kill. It was found later that T-21 group (ACT-1) varieties did not fit completely in this rotation because of their tendency to spill over into the wheat planting season. Two new genotypes — Prabhat, a selection from T-21, and UPAS-120 a selection from P-4758 — that fit well into this situation were identified (Ramanujam and Singh, these Proceedings). Later work has been concerned with breeding pigeonpea varieties that are earlier, with better yields, and are also free of drawbacks such as small seeds and marked susceptibility to insect pests, particularly pod borers. This program has been particularly intensive at the Delhi, Ludhiana, and Hissar centers of the Project.

At the Division of Genetics, IARI, New Delhi, breeding work was started in 1976, with specific emphasis on evolving high-yielding short-duration types. In addition to earliness, the major objectives are:

- short, compact, and erecttypes suitablefor intercropping;
- nondeterminate habit;
- synchronization in maturity;
- photo- and thermo-insensitivity;
- resistance to pod borers and wilt; and
- bold white seeds.

The parents used in the crossing program were Prabhat, UPAS-120, Pant A-3, a soy type obtained from IITA (Nigeria), Khargone-2, HPA-2, Pusa Ageti, T-21, an Australian photoinsensitive selection from Pant A-8, and more recently, very bold-seeded and long-podded vegetable types such as 8504.

Progenies of the cross, Khargone-2 x Pusa Ageti, gave very promising segregants. A high-yielding and early (150 days) genotype that has given good performance in ACT-1 trials is DL 74-1, which has since been recommended for release by the 1978 Kharif Pulse Workshop of the Project. Two extra early varieties, DL 78-1 and DL 78-2, were developed from Pant A-3 x UPAS-120 and have been entered in EACT trials. DL 78-1 has a more or less determinate habit; is relatively dwarf, compact, erect, earlier even than Prabhat; and has bolder seed. DL 78-2, of indeterminate habit, is a tall erect type. It is about 10 days earlier than UPAS-120 and has bolder seed. In the 150-day maturity group.

two selections — 4-84 from the cross Pusa Ageti x T-21 and 4-64, a spontaneous outcross in T-21 — have given superior performance in the Coordinated Trials and are presently being tested in adaptive/minikit trials.

At Ludhiana, the major objective has been to evolve early-maturing types that can fit well in rotation with normal sown wheat and give high and stable yields. Attention is also paid to resistance to the pod borer complex and podfly, because the attack of these insect pests is more severe on early-maturing types. A variety AL-15 was identified, which on an average of 5 years' results has given a grain yield of 1400 kg/ha against 1100 kg/ha of T-21. AL-15 is earlier than T-21 by about 2 weeks, is determinate, and has a relatively dwarf and compact habit.

From similar programs at Hissar, several elite genotypes have been selected. H-73-20, maturing in 140 days, is determinate, sernicompact, and dwarf. The podding is confined to top of branches and seeds *are* medium bold (8.8 g/100 seeds). Hybridization between early x early and early x medium varieties followed by disruptive selection has been practiced to break the association between lateness and yield. During kharif 1977, 54 bulked and homozygous lines — emerging from crosses, Prabhat x UPAS-120, H-72-44 x Prabhat, T-21 x UPAS-120, and H-247 x Prabhat — were tested in three trials. In the indeterminate group nine selections (H-76-23, H-76-29, H-76-20, H-76-28, H-76-18, H-77-208, H-77-213, H-77-205, and H-77-164) were found significantly superior to UPAS-120, with yields ranging from 2900 to 3800 kg/ha compared with 2300 kg/ha of UPAS-120. in the determinate group, H-76-40, H-76-44, H-76-54, H-76-32, H-76-35, H-76-68, H-76-70, H-77-169, and H-77-144 were superior to the check, Prabhat.

Another interesting development made possible by the availability of the EACT group of varieties is the extension of pigeonpea cultivation to Rajasthan, particularly in the command area of the Rajasthan Canal Project. Since this region has limited rainfall, water for crop growth has to be provided through canal irrigation. It is therefore possible to control moisture availability and hence determine the data of harvest precisely. Under such situations, the EACT variety UPAS-120, has shown good performance and has gained substantial farmer acceptance. It would appear possible, however, that higher yielding genotypes, even more closely fitted to this situation, could be developed. ACT-1 types themselves could prove superior or could yield suitable types following an appropriate program of hybridization-cum-induced mutagenesis. It is clear, however, that such intensive breeding can be done only in the concerned agroecological niche. Unfortunately we do not have a suitable setup in this area as yet under the All-India program.

Shifting Pigeonpea to New Niches in Time

It has been shown in the Indian program as well as at ICRISAT that shifting the pigeonpea crop in time also holds great promise for increasing the area and thus the production of this important pulse crop. One possibility, for instance, is to shift the sowing of the pigeonpea crop to the premonsoon months, rather than sow in the conventional last week of June or first week of July. Research carried out at the Kanpur center of the Indian program has suggested that sowing pigeonpea T-21 a couple of months earlier, say the beginning or middle of April, with irrigation, can help to increase yields appreciably (Table 8). Three to four rows of mung T-44 are intercropped between pigeonpea T-21 planted at 120 cm, using half the conventional seed rate for pigeonpea. Not only can an intercrop of mung bean be taken and substantial quantities of dry pigeonpea stalks harvested in addition to grain, but the pigeonpea may be harvested well in time for the sowing of the succeeding winter crop, usually wheat. In this situation the pigeonpea plants are highly vegetative, which poses problems in managing such operations as spraying with insecticides, and there is much scope for genetic manipulation of the pigeonpea component so that it becomes more manageable. This practice should have potential in western Uttar Pradesh. Breeding and evaluation of such pigeonpea genotypes for such a situation has begun in the Indian program (see Table 5 of Ramanujam and Singh, these Proceedings).

It is also possible to shift the crop to the postrainy or winter (rabi) season. This is not an entirely unknown practice, since it is adopted in some areas of India such as Gujarat and in the Nepal *terai.* Such shifting has, as expected,

Table 8. Grain yields in two multiple cropping patterns at Kanpur In 1977-78.

Cropping partem			Grain yield (kg/ha)		
Premon8oon	Monsoon	Winter	Mung bean	Pigeonpea	Wheat
(Pigeonpea	+ Mung bean)	Wheat	1400	2500	6700
Mung bean	Pigeonpea	Wheat	1300	1700	5600

Source: Panwar and Yadav (1978).
Mung T-44; pigeonpea T-21; wheat HD-2177.

precisely the opposite effect to premonsoon sowing. Late varieties that grow tall and bushy in monsoon planting flower earlier and put on less vegetative growth when planted in September-October. Consequently the crop is more manageable, responds better to population pressure and irrigation, and has a better harvest index than the monsoon planting, resulting in better yields. Early and medium-late varieties, on the other hand, are stunted in their growth and give relatively poor yields compared with their yields in kharif planting. Experiments at ICRISAT in the 1976 and 1977 season have also given similar results.

In the Indian program we have begun evaluating a range of genotypes for their suitability to delayed planting. Table 9 presents the results of one such varietal evaluation at Dholi (Bihar) for the September-sown crop. EACT and ACT-1 group cultivars flower and mature at almost the same time, but the EACT varieties failed in July sowings due to podfly damage. These two groups do not differ appreciably in grain yield. The late varieties, however, changed completely in their morphology, becoming dwarfer, and matured 50 to 70 days earlier than when sown in June. They have also given much higher yields. However, even in this group, genotype x sowing season interaction is evident (Table 9). September-sown pigeonpea can vacate the land well in time for many economically attractive rotations (Roy Sharma et al. 1980). In the Indian program, a wide range of genotypes have been tested in this planting season in 1980. (Ramanujam and Singh,these Proceedings).

Interesting results have also been reported (Misra et al. 1980)on the behavior of EACT and ACT varieties from Orissa, when sown at the end of September in rice fallows (Table 10).

EACT and ACT-1 varieties have given poorer performance than the Nayagarh Local, which is medium late. Here also reduction in vegetative growth (dwarfer, less branched plants) and earlier flowering are apparent. Both these effects are more marked for the late type than for the earlier maturing types, except in the case of primary branches in NGR Local. Because of the reduced vegetative growth, the production of dry matter is much less than in the normal sowing. However, grain yields are as good, if not better, so that the harvest index is higher than that in the kharif season.

Interestingly enough, a more or less similar situation is encountered when pigeonpea is intercropped with sorghum. Willey and Natarajan (1980) have reported that the harvest index in intercropped pigeonpea is better than in pure pigeonpea, though the production of dry matter is appreciably greater in the latter situation.

Enough has been said to demonstrate the extreme plasticity of the taxon. There is also enough evidence of the exciting possibilities open to the breeder to tailor the crop to various climatic and agroecological situations. It is quite likely that in the new niches, new pest and disease problems will arise and call for incorporation of resistance by appropriate breeding procedures. For example, September-planted pigeonpea has been reported to suffer from Alternaria blight in a few pockets while in other areas sterility mosaic has appeared in an unexpectedly severe form. The scientists in the Indian program, however, are confident that these challenges can be met adequately.

References

ANONYMOUS. 1978. Summarized results of the All India Coordinated Trials conducted during kharif

Table 9. Performance of pigeonpea varieties of different maturity groups in September sowings at Dholi. Bihar, india, kharif 1977.

Varieties	Days to flower	Days to maturity	Grain yield (kg/ha)	Production/day (kg/ha)
EACT				
UPAS-120	71	157	1330	8.5
Prabhat	69	160	1190	7.4
Pant A-4	72	160	1570	9.8
Pant A-1	72	160	890	5.6
TT-6	72	162	1430	8.8
ACT-1				
BS-1	73	162	1330	8.2
T-21	73	162	1430	8.8
ACT-2				
S-8	73	162	1570	9.7
ACT-3				
2-E	142	234	1430	6.1
Basant	123	212	3380	15.9
Bahar	138	212	3430	16.2
LSD			104	

Source: Roy Sharms et at. (1980).

Table 10. Performance of pigeonpea varieties of different maturities in July and September sowings in Orissa, India.

Variety	Duration (days)			Plant height (cm)			Primary branches (no.)			September yield (kg/ha)	
	July	Sept	Reduction	July	Sept	Reduction	July	Sept	Reduction	1975	1978
EACT											
Prabhat	110	106	4	126	59.5	66.5	6.4	4.0	2.4	1265	243
UPAS-120	119	112	7	180	74.0	106	9.8	4.5	3.3	981	660
ACT-1											
BS-1	146	123	23	212	71.0	141	11.1	4.5	7.6	1200	616
T-21	146	124	22	201	82.5	118	12.3	3.5	8.8	1370	711
S-5	154	106	45	152	77.5	84.5	10.4	3.5	6.9	1370	885
ACT-2											
NGR Local	223	133	90	325	107.5	216.5	11.4	6.5	4.4	1474	788

Source: Misra et al. (1980).

1977-78. *In* Proceedings, kharif Pulses Workshop, AICORPIP, 1978, Baroda, India. (Mimeographed.)

DONALD, C. M., and HAMBLIN, J. 1976. The biological yield and harvest index of cereals as agronomic and plant breeding criteria. Advances in Agronomy 28: 361-408.

FRANCIS, C. A., PRAGER, M., and LAING, D. R. 1978a. Genotype x environment interactions in climbing bean cultivars in monoculture and associated with maize. Crop Science 18: 242-246.

FRANCIS, C. A., PRAGER, M., LAING, D. R., and F LOR, C. A. 1978b. Genotype x environment interaction in bush bean cultivation in monoculture and associated with maize. Crop Science 18: 237-242.

KRISHNAMURTHY, CH., CHOWDHURY, S. L., and ANDERSON, D. R. 1980. Intercrop systems with particular reference to pigeonpea-sorghum. Indian Journal of Genetics 40A: 56-61.

LAXMAN SINGH. 1980. Prevalent practices of mixed cropping and cropping systems of pulse crops in india. Indian Journal of Genetics 40A: 1-5.

LAXMAN SINGH, and SHRIVASTAVA, M. P. 1976. Cultivation system and varietal adaptations of pigeonpea in Madhya Pradesh. Indian Journal of Genetics 36: 293-300.

LAXMAN SINGH, TIWARI, A. S., SHRIVASTAVA, M. P., SHARMA, H. K., and SINGH, B. R. 1978. Breeding studies in relation to cropping systems in pigeonpea. *In* Proceedings, Kharif Pulses Workshop, AICORPIP, 1978, Baroda. (Mimeographed.)

LAXMAN SINGH, TIWARI, A. S., YADAV, L. N., SINGH, L., and MAHADIK, C. N. 1977. Spreading plant type does better in pigeonpea. Tropical Grain Legume Bulletin 7: 7-10.

MEHTA.T. R. 1970. General, *In* Pulse Crops of India, ed. P. Kachroo. New Delhi, India: Indian Council of Agricultural Research.

MISRA, R.C., TRIPATHI, D., and MISRA, R. C. 1980. Extra early and early maturing arhar in cropping systems in Orissa. Indian Journal of Genetics 40A: 157-162.

PANWAR, K. S., and YADAV, H. L. 1978. Response of short duration pigeonpea (Var. T-21) to summer planting and phosphorus in the parallel multiple cropping. *In* Proceedings, Kharif Pulses Workshop, AICORPIP, 1978, Baroda, India. (Mimeographed.)

RAMANUJAM, S. 1973. Grain legume improvement in India. *In* Proceedings, First IITA Grain Legume Improvement Workshop, IITA, Ibadan, Nigeria.

RAMANUJAM, S., and SINGH, S. P. 1980. Pigeonpea breeding in the All India Coordinated Programme. Session 10, Volume 1, these Proceedings.

ROY SHARMA, R. P., THAKUR, H. C, and SHARMA, H. M. 1980. Potentialities of September sowing of pigeonpea. Indian Journal of Genetics 40A: 254-258.

SHAW, F. J. F., KHAN, A. R., and SINGH, H. 1933. Studies in Indian pulses. The type of *Cajanus indicus* Spreng. Indian Journal of Agricultural Sciences 3: 1-36.

SHELKE, V. R., and KRISHNAMURTHY, CH. 1980. Studies on crop geometry in dryland intercrop systems. Indian Journal of Genetics 40A: 71-75.

TARHALKAR, P. P., and RAO, N. G. P. 1980. Genotype-density interactions and development of optimum sorghum-pigeonpea intercropping. Indian Journal of Genetics 40A: 49-53.

WILLEY, R. W., and NATARAJAN, M. 1980. Some aspects of resource use in sorghum/pigeonpea intercropping. Indian Journal of Genetics 40A: 6-13.

Discussion — Session 2

Parpia:

Or. Sharma's table provided data up to 1975. FAO can provide information on production only when the governments provide it. With regard to production figures for African countries, I would be glad to provide the latest information, including estimates for 1980.

Sharma:

Your offer is very welcome, as published statistics were only available for the year 1975. FAO stopped publishing information on pigeonpea in subsequent years.

Joshi:

We need todefine — through multilocation phenological studies, as ICRISAT is doing for grain sorghum — agroclimatic parameters for which a common set of varieties may be pooled for common tests in ICRISAT's international program and ICAR's AICPIP. Selecting for a certain location or cropping system is certainly important, and will give immediate results of economic value, but determining criteria or indices for such selection would give a direction to the selection program.

Ramanujam:

Multilocation testing of a common group of varieties at different locations is an integral part of the ICAR program. Data on flowering and other developmental characters are available and used in evaluation, keeping in view the agroclimate of the locations. Identifying a new niche and locating a genotype to fit its agroclimatic limits has been and must be the first step. This has been followed by tailoring the genotypes to come closer to those limits; a good example is the development of T-21, followed by Prabhat, UPAS-120, and still better Haryana and Delhi varieties in that order, where the succeeding varieties are better in adaptation, seed size, insect pest resistance and possibly in yield. Similarly, in intercropping we have evidence of differential response to sorghum/bajra/maize competition of old and new pigeonpea genotypes. We also have evidence of better performance of newly bred genotypes for April planting, and trials are on to screen varieties and populations for rabi conditions. We do come across new problems, but there is no doubt that we can overcome these.

D. Sharma:

Testing of a common set of varieties of pigeonpeas across a wide range of agroecological situations at the international level is somewhat difficult to operate, because of specific local needs of season, cropping system, etc. Grouping material and trying a large array of types, as we did in the ICRISAT adaptation trials, provides necessary information for constituting specific trials for specific regional and cropping system requirements. Now most of the ICRISAT trials are formulated on that basis. Our experience shows that, on a broad basis, adaptation of a particular group in a specific region can be extended from results obtained at Hyderabad. However, choice of variety and selection will have to be done at the specific location.

Regarding selection of breeding material within the cropping system in which the crop is used, we have done some work to determine whether such selection in the early stages is essential or likely to give rapid genetic advance. It is discussed to some extent in a later paper at this Workshop on breeding of pigeonpeas at ICRISAT (Session 10, Green et al.), but the information is not yet conclusive, and needs further study. However, the evidence from other work at IITA on cowpea, at CIAT on *Phaseolus* beans, and on mung beans at IRRI shows that a more practical and dependable approach may beto select in pure stand at early stages, followed by testing in both sole and intercrop systems. This is because heritability foryield is low, and it is further reduced in the more complicated system of intercropping, where several variables are involved and are difficult to control. A pure-crop system is certainly simpler. Indications are that varieties best in one system are also among the top in the other system; correlations are fairly high if material under test is of a similar maturity group. Thus, little will be lost if a good number of genotypes are included in the final testing in the system.

Keatinge:

Referring to Table 6 in Dr. Sharma's paper, what is the effect of environmental factors on stability in grain weight?

Sharma:

In the rabi season, seed weights are usually lower than in the kharif season. But the relationships between cultivars remained similar. This indicates that growing season and environmental factors do affect seed weight, but it is not of much consequence with regard to the relative characterization of genotypes at ICRISAT.

Laxman Singh:

Breeding of pigeonpea would be considerably helped by a better understanding of the plant. Three aspects to consider are: (1) breeding behavior or reproductive system; (2) adaptability to soil moisture variation; (3) homogeneous or heterogeneous populations. Such information would be useful in a breeding program.

Paroda:

The role of photoi nsensitive types for wider adaptation has been emphasized. However, the existing relationships between late duration and high yield in existing cultivars should perhaps caution us to not to lay too much stress on photoinsensitive types but to select photosensitive types suitable for varying agroclimatic conditions until high-yielding photoinsensitive types are evolved. This appears to be a rather difficult task unless undesirable linkages between earliness and yield can be broken.

Sharma:

I think I have not been understood properly. Photoperiod-insensitive types are not being proposed for wider adaptation of the crop in the sense of wider adaptation of a particular variety, as in the case of wheat or rice. For pigeonpeas, such types may be useful in extending the crop to unconventional areas such as short-season cropping in temperate regions or summer cropping with irrigation in tropical and subtropical regions. We are talking about the use of these types in highly specific conditions, where season-bound varieties are required.

Sheldrake:

What do we need to do to establish effective analysis of international adaptation of pigeonpeas? Is investment in adaptation analysis justified?

Byth:

Certainly. Our understanding of the potential of the different production systems regionally is relatively poor, primarily because we do not have a good understanding of the environmental factors influencing growth and development and of the plant characters influencing the response of genotypes. The primary purpose of regional trials is to expose a diversity of genetic material regionally, so that genotype performance can be considered in terms of environmental factors. This implies collection of at least a minimal data set to help analyze the causes of differences in response to environments. The basic point is that effective plant improvement requires (1) the identification of the relative merit of the different production systems in a region, and (2) the progressive explanation of the differences in genotypic response. Thus, subsequent cycles of plant improvement can be conducted more effectively; i.e., improvement objectives can be defined more rationally and attacked more sensibly.

Whiteman:

Should the organizers of international variety trials define more clearly the basic parameters of the trial, i.e., time of planting, density of sowing, and phenotypic data to be collected?

D. Sharma:

In the national program, each group can plant the trial according to local agronomic practices, to give some information on the suitability of the material. If possible, the material should be observed at different locations to help us understand the disease and insect problems of particular locations.

Byth:

Adaptation analysis is most important. The argument here is over the priorities in the plant improvement: Is it more important to distribute the genetic material or to understand the causes of differences in performance? If we are to do a better job in the next cycle of plant improvement, we should understand how the genetic advances we made this time have come about. We should also know the basic cause of differences in adaptation so that we can build that knowledge into our breeding program. We can consider yield alone first; this will give some useful information to the plant breeder for that character only. If we take phenology as the next character, we are going to cope with the proportion of interaction in adaptation.

D. Sharma:

In my opinion, ICRISAT should not attempt to breed material for all specific situations. We should give the material to the national programs to do their own selection and make their own decisions.

Gupta:

In your paper you have indicated that you are using 8509, a very bold-seeded and long-podded vegetable type in the crossing program. Can you tell us the details of this line as far as days to flower and maturity and plant type are concerned?

Ramanujam:

This should be 8504, and not 8509.8504 is a long-podded type introduced from ICRISAT.

Session 3

Entomology

Chairman: H. P. Saxena

Rapporteurs: S. S. Lateef
S. Sithanantham

Pest Management in Low-Input Pigeonpea

W. Reed, S. S. Lateef, and S. Sithanantham*

Abstract

Surveys of more than 1000 fields of pigeonpea, Cajanus cajan *(L) Millsp., across 13 states of India from 1975 to 1980 have indicated that over 80% of this crop is grown as a component of mixed or intercrops, with few or no purchased inputs. Although the insect-caused damage was found to be generally severe, less than 5% of the surveyed fields had been protected by pesticides. Endosulfan is generally recommended for use against the major pest,* Heliothis armigera, *but most farmers who used pesticides used only DDT or BHC. Prospects for improved pest management in the prevailing low-input situation are discussed in the light of research results from ICRISAT and elsewhere. It is suggested that group action by farmers to synchronously sow less susceptible cuttivars and improved techniques for the timing and application of pesticides should form the basis of further pest-management research at the village level. Augmentation of natural control elements — including parasites, predators, and insect pathogens — also appears to have some potential; however, there is great variation in the crop and pest ecology across India, and pest management will have to be tailored to the local conditions. Hence, extensive data collection is needed from various areas.*

Pigeonpea, *Cajanus cajan* (L.) Millsp., is of importance as a source of high-protein food in many countries in the semi-arid tropics, but particularly so in India, where it is the second most important pulse (after chickpea) and where 92% of the world's recorded production is grown. The plants have a perennial potential but are usually grown as annuals. They are slow-growing shrubs with extended flowering and podding periods, generally producing very many more flowers than can be held as pods (Sheldrake et al. 1979). A large number of insects have been recorded as feeding on this crop (Bindra 1968; Davies and Lateef 1975), and several can achieve pest status in some areas and in some years. In general, the complex of insects feeding on and in the pods cause the greatest loss; earlier damage to foliage, buds, and flowers can usually be fully compensated by extended growth, provided the growing conditions remain favorable.

* Pulse Improvement Program, ICRISAT.

Surveys in India

There are several reports of quantitative estimates of losses caused by insect pests on pigeonpea from various parts of India, and a few from other countries, but these are mostly calculated from specific trials in the atypical environments of research farms. There appeared to be no reports of survey data from farmers' fields on an all-India basis, utilizing standard methods, from which losses to individual pests could be quantified. Consequently Davies and Lateef initiated surveys of farmers' fields in the major pigeonpea areas of India in 1975. These have continued to 1980, and we are now in the process of analyzing the data for publication, but a few of the relevant statistics from these surveys can be usefully quoted here.

Data from more than 1000 farmers' fields showed that 79% were mixed or intercropped, with the component ratio varying widely. In most cases, the pigeonpea is sown in rows at the same time as the companion crop, which is usually harvested before the pigeonpea comes to the podding stage. Where the pigeonpea rows are in a 1:1 or 1:2 ratio to the companion crop rows, the pigeonpea can grow on to give full ground cover. In many cases, however, the pigeonpea is a minor intercrop component and at the time of podding and harvest is left as wide-spaced rows with plenty of bare ground in between. The problems of pest management on such wide-spaced rows of pigeonpea can be very differentfrom thoseprevailing inthedense monocrop situation. When we add to this the vast range of landrace cultivars, with greatly differing maturities and plant habits, and the wide geographic range, with attendant variation in climate and pest complexes, we are confronted with a very wide range of pest-management situations. Thus, we are very conscious of the dangers of generalizations on the pest management of this crop and strongly advocate the formulation and testing of packages in the farmers' fields in each target area.

Generally, we survey crops at the maturity stage, timing our surveys to visit farmers' fields just before harvesting. Pod samples are collected and brought back to our laboratory, where they are carefully examined for damage by the various pests. Table 1 shows the mean data from these pod samples.

Table 1. Percentage of sample pigeonpea pods at maturity stage damaged by Insects in farmers' fields, 1975-80.

	Percentage of pods damaged by			
	Lepidoptere	Podfly	Hymenoptera	Bruchid
Northern states (272 fields)	12.6	19.1	0.1	0.3
Central states (289 fields)	30.0	24.8	3.0	3.6
Southern states (362 fields)	34.1	9.0	2.1	7.2

The losses are mainly caused by the pod borer, Heliothis armigera (Hb.) and the podfly, Melanagromyza obtusa (Mall.), with the former pest often virtually destroying the crop in the southern states of India. Indeed, many farmers' pigeonpea crops are so badly devastated by the insect pests that one must question why farmers in south India continue to grow such a crop. Pigeonpea dhal is, by taste and tradition, an essential component of the farmers' diet, so even very poor harvests may be sufficient return for the work involved in growing the crop. In addition, however, the stems provide valuable fuel and most farmers are well aware of the beneficial effects of pigeonpea on their soil and on the subsequent crop. Many farmers are particularly concerned about the devastating losses that can be caused by Heliothis and several have told us that they are so desperate to protect their crops against this pest that they employ laborers and children to collect and destroy the larvae or to shake the bushes to dislodge them.

Insecticide Use

With such large losses to pests, there is an obvious potential for pesticide use. There have been numerous studies of the use of a large range of pesticides on this crop, at centers throughout India and in several other countries, and many show impressive yield returns. Most reports only mention data collected from small plot trials on research farms and the yield increases shown in these trials may have little relevance to the farmers' fields. However, there are reports of substantial yield increase from insecticide use on farmers' field demonstration in some areas.

Insecticide Use in Farmers' Fields

In India, recommendations for pesticide use on this crop have been formulated by several state agricultural extension departments and by agricultural universities. The most commonly recommended are endosulfan and/or monocrotophos, the former being most effective against H. armigera and the latter against M. obtusa. In our surveys, however, we found that less than 5% of the pigeonpea farmers used pesticides and that almost all of these used DDT or BHC in dust or wettable powder form. These pesticides are relatively easily available and cheap, which is probably why they are more widely utilized than the less polluting pesticides recommended.

The reasons for this low rate of pesticide use are of obvious interest; to determine them we need a socioeconomic survey. For a few years, the price of pesticides increased faster than did

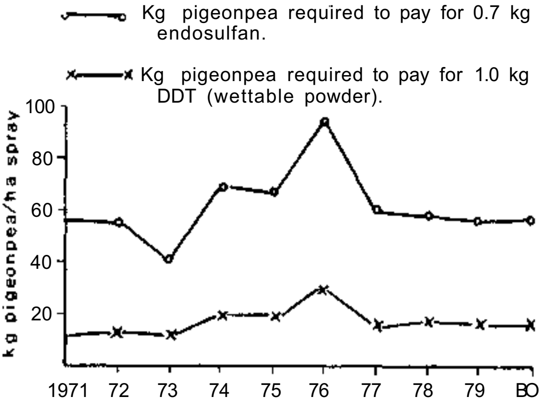

Figure 1. Costs of insecticides, expressed as kg pigeonpealha, at rates effective against Heliothis *larvae.*

the market value of pigeonpeas as shown in Figure 1. But more recently, a continuing shortage of pulses in India has forced up market prices of pigeonpea to a point where it would appear to have potential as a cash crop well worth growing with purchased inputs, including pesticides.

Problems of Insecticide Application

Although several insects attack the leaves and stems of pigeonpea in the vegetative phase, the crop has a marked ability to compensate for such damage, so there appears to be little profit in using pesticides beforethe flower-bud stage. At the flower-bud stage, when insecticide use may well be profitable, a monocrop of most landraces of pigeonpea will be 1.5 m or more tall and densely branched. The buds, flowers, and pods, which are the target for the protective chemicals, are in the upper portions of the plants, thus requiring the farmer to spray or dust above shoulder level. It is difficult to push one's way through a well-grown monocrop of pigeonpea with both hands free, let alone operate a sprayer or duster to give a reasonable distribution of pesticide on the target. In addition, many farmers have told us that they are reluctantto walk through pigeonpea because of thedanger of snakes. Theproblems are reduced in intercrops, where the companion crops are harvested before pest control is required on the pigeonpea, so providing convenient paths through the crop. However, most experimentation with pesticides appears to have been concentrated on monocrops, and the optimum application rates and economics of pesticide use on intercropped pigeonpea may require special study.

Most pigeonpea crops reach the flowering stage well after the rains have ended and water is seldom readily available in large quantitites close to the fields. The spraying recommendations in most areas are still for high volume, requiring up to 600 liters/ha. This is not a problem on most research farms, where there is a piped supply and a tractor to carry water to the field, and where laborers are paid to spray the small experimental plots. In the real world, however, the farmer finds the use of high-volume sprays on pigeonpea a very arduous task.

Many farmers use insecticide dusts, others make ingenious use of bullock carts as spraying platforms for high-volume, rocker-type sprayers. A few farmers drift pesticides into their pigeonpea crops, using expensive motorized knapsack sprayers that have been primarily purchased for use on cash crops such as cotton or vegetables. All too often, the farmers spray too late, after they have seen the damage. Ideally, spraying against *Heliothis* should start as soon as large numbers of eggs are seen.

It is probable that most farmers use no pesticides, not because they are unaware of pest losses or of the benefits to be obtained from pesticide use, but because they do not have ready access to a practical, economic package of pesticide application.

The Future of Pesticide Use

There is a need to make the use of pesticide on pigeonpea easier and more effective. Spraying from the air has been suggested but would appear to have limited practicality, if only because of the costs and organization involved. The use of ultralow-volume (controlled droplet) applications (Matthews 1979) would appear to be attractive, for this sprayi ng would reduce the need for the sprayman to force his way down every row and it would also solve the problem of water supply. Unfortunately, reliable ultralow-volume applicators giving the required droplet size (approximately 70 microns) are not yet readily available in India and several other pigeonpea-producing countries, nor are the appropriate oil-based formulations of pesticides that would be required for this type of spraying. In many areas, wind speeds during thef lowering period of this crop exceed 10 mph, which is greater than the limit at which this type of spraying can be used, so it will not develop as a panacea.

The answer to the access and coverage problem in pigeonpea is to redesign the crop so that it is no more than 1 m tall at flowering. This is a challenge that has been taken up by our breeders and physiologists. The ideotype for a pigeonpea plant designed for pesticide protection can be briefly described as a small plant with an exposed flowering and podding canopy, the flowering and podding period being as short as possible so as to reduce the period of protection and hence the number of sprays required.

There is a volume of opinion, but little reported evidence, that *H. armigera* in some parts of India has developed resistance to the commonly used pesticides. However, trials at many centers in India, including ICRISAT, have indicated that the new pyrethroids are particularly effective against the pest complex on pigeonpea, so we have a new generation of pesticides that could serve us well on this crop in the near future. Unfortunately, these pesticides are relatively expensive and therefore are most likely to be used primarily on the high-value cash crops such as cotton and vegetables. Pyrethroids, like most chemical pesticides, will not spare the beneficial insects. We are concerned about the effect of pesticide on the populations of the natural control elements and are studying this at ICRISAT.

Even if we overcome the problems of pesticide use on pigeonpea to such an extent that most farmers are able to benefit, evidence from elsewhere should convince us that it would be folly to rely completely upon insecticides for pest control, particularly for *H. armigera. Heliothis* spp. have already caused chaos in parts of the Americas and Australia, where indiscriminate use of pesticides resulted in a high resistance in these pests so that crops had to be abandoned. The podfly is not an easy target for pesticide use, for all stages of this pest, except the adult, are inside the pods, where they are protected from most pesticides. Thus, while we should give due attention to the discriminate use of pesticides on pigeonpea, we should also explore alternative control* elements.

Potential for Pest Management with Little or No Pesticide Use

As most pigeonpea farmers currently use no pesticides, it might be prof itable to seek alternative strategies of pest management. There would appear to be several elements that could be of practical utility in integrated schemes.

First, it is essential to obtain a basic knowledge of the potential pests for which management is to be undertaken. A knowledge of the ecology of those pests and the likely annual incidence of their populations is indispensable. If, for example, the peak populations of *H. armigera* are known to occur regularly in a particu tar month, then it may be useful to sow a pigeonpea cultivar with a maturity that ensures that the vulnerable flowering and podding period will avoid the worst of the pod-borer attacks.

With polyphagous pests such as *H. armigera,* we must study the populations not only on pigeonpea, but also on all other hosts in the area, including cotton, cereals, other legumes, vegetables, and several weeds. The local populations of this pest may also be enhanced or reduced by migration; to track such migration, we are trying to set up a network of light traps across India, from which the moths of *H. armigera* and other pests can be recorded. Some workers consider that light traps can be of use in the direct control of *H. armigera* but we do not consider this feasible. We are cooperating with Dr. Nesbitt of the Tropical Products Institute, UK, in developing pheromone studies of *H. armigera.* A monitoring system using pheromone traps would offer several advantages, and the pheromone might eventually provide us with a means of control.

We urgently need more data on the ecology of *H. armigera* and its natural controlling elements in the large parts of the world where it is a major and increasing pest. We are attempting to establish a "bank" for such data here at ICRISAT. In the higher latitudes, cold winters reduce this pest to a low ebb each year, but a small proportion of the population probably struggle through in the form of overwintering pupae. Closer to the equator, the long hot dry summers of the semi-arid tropics greatly reduce this pest each year. There is a fear, however, that the increasing use of irrigation in the tropics may well provide food for this pest throughout the year, leading to catastrophic increases in populations. On the other hand, a year-round availability of the larvae might provide an opportunity for the parasites and predators to thrive and so hold the pest populations to much lower levels, as Coaker (1959) suggested was the case in Uganda.

Unlike the pod borer, the podfly (*Melanagromyza obtusa*) is oligophagous, so the problems of understanding the population dynamics of this pest do not appear to be so formidable. The prospects for managing this pest by reducing its alternative hosts and restricting thepodding period of pigeonpea inany area appear promising.

In areas where pest attacks are erratic, and where the pigeonpea growing season is not abruptly terminated by a cold winter or a shortage of moisture, cultivars with a potential to compensate for losses incurred early in the season will be of considerable value. Such a mechanism can be seen to be of greatest value in the area where *H. armigera* is the dominant pest and of lesser value where the podfly is dominant, for in general, the laterthe crop, the greater the podfly damage.

Here we are advocating the system that has been evolved in farmers' fields over centuries. In most areas it is evident that the duration of the local landrace cultivars is at an optimum to fit the combination of climate and pest attack. In many cases the landraces compensate well for early pest attacks. This does not mean that we cannot improve upon these evolved systems or cultivars, but it should certainly warn us not to meddle with the farmers' crops until we are convinced that our improvements really will give stable benefits. All too often modern man has rushed in with new practices that appear beneficial in isolation but which threaten the stability of evolved integrated systems.

Use of Resistant Cultivars with Synchronized Sowing

The use of cultivars resistant to the major pest complexes in each area would be a significant step toward successful pest management. But in spite of intensive effort at ICRISAT (Lateef and Reed these Proceedings), we are still a long way from producing plants that are anywhere near immune to attacks from either pod borer or podfly. However, we and other workers in India do have selections that differ widely in their susceptibility to the pest complex, and derivatives of some of these could be of practical use in farmers' fields in the near future. Cultivars selected for their yield performance under pesticide umbrellas on some research stations are unlikely to be of utility in most farmers' fields, where no pesticides are used.

The synchronous sowing of a resistant cultivar at the optimum time by all farmers in an area promises to be a major step in any pest management strategy. With such a measure, the pest populations will be diluted across the crop area at any one time, with a minimum opportunity to build up by dispersing from earlier to later crops.

What is the possibility of achieving synchronous sowing in an area large enough to obtain demonstrable benefit? Some success has already been achieved by encouragement of the synchronous sowing of cotton at the village level in Tamil Nadu (V. R. Menon, personal communication). For such a tactic, it is essential first to determine the optimum time of sowing applicable to the chosen area and cultivar and then to persuade all the farmers in that area of the advantage of such cooperative action. Such a tactic is undoubtedly risky, and any mistake in promoting group action could be disastrous. Thus in any area of intended management adequate data collection and evaluation must precede management action. Here there is a role for the agronomist, the economist, the sociologist, and others, for not all facets of pest management are the sole responsibility of the entomologists.

Natural and Biological Control

Many of the species of insects and other animals found on pigeonpea are not pests. Several are beneficial, for they feed upon the pest complex. At ICRISAT, for example, we have identified 24 species of parasites on *H. armigera* (V. S. Bhatnagar, personal communication) and seven species on the podfly. In addition, many pests face a violent end in the jaws of predators such as spiders, other insects, lizards, and birds. The recorded list of the enemies of *H. armigera* is so long that we question how this pest can survive, let alone build up to such devastating numbers.

Our understanding of the population dynamics of pigeonpea pests and their natural enemies is still very limited. We do not have enough data to enable us to model the effects of the natural enemies upon the pest complex. We do know that in our pesticide-free areas at ICRISAT, *H. armigera* larvae are present in large numbers on pigeonpea from October through February and that the natural enemies have not built up to levels that can crush these populations.

On other unprotected crops, including sorghum and cotton, it is generally observed that *H. armigera* populations are relatively short-lived, with the natural enemies — particularly the egg parasites — playing an important role in the reduction of the pest. Bhatnagar and Davies (1979) have shown that in intercrops of sorghum and pigeonpea, the parasites common in the eggs of *H. armigera* on sorghum do not transfer or disperse to the eggs of the pest on pigeonpea. We need to find out why the natural enemies appear to be so inefficient on pigeonpea. It has been suggested that pigeonpea is relatively resistant to many potential pests by virtue of its citronella-type odor (A. R. Sheldrake, personal communication). Perhaps we should be looking for pigeonpea plants that are less repellent to insects!

We still have to find means of increasing the efficiency of the natural enemies of the pests or of introducing new and effective biological agents. Our first concern has been to collect data and try to understand the present natural control situation on this crop. While this phase of our work is by no means complete, we have also begun efforts to introduce other elements.

In cooperation with the Directorate of Plant Protection of the Government of India, the National Institute for Biological Control, Bangalore, and the Commonwealth Instituteof Biological Control, Bangalore, we are attempting to establish a parasite of *Heliothis* spp. that was imported from the USA. We are now able to culture this tachinid fly, *Eucelatoria* sp., in our laboratory through the year in quite large numbers and are currently attempting to establish it in our fields. This may well be the first of many attempts to utilize exotic parasites and predators. We would certainly like to find a parasite that will thrive on *Heliothis* eggs laid on pigeonpea! Most successes of biological control have been on islands with recently introduced pests and/or on perennial crops. We appreciate that there have been few real successes on old-established pest situations such as that of *H. armigera* on pigeonpea, but the cost of trying is relatively small, and the potential returns so great that we must continue efforts in this direction.

Pest insects, like man, are subject to lethal diseases that can greatly reduce populations. In China, some village communes have units that are concerned with the production and utilization of insect disease organisms in a simple but apparently effective manner (Anonymous 1977). In the USA and Australia, nuclear polyhedrosis virus, which is specific to some *Heliothis* spp., is now available commercially. The purification of this virus to an acceptable standard contributes to the cost of the commercial product and so provides a relatively expensive means of *Heliothis* reduction. The value of such an insecticide lies in its specificity and minimal effect on nontarget animals. In developing countries such as India, the high cost of purified commercially produced virus (and of other biological pesticides including *Bacillus thuringiensis)* for *H. armigera* control would appear to outweigh the environmental advantages at this time and would, in any case, offer application problems similar to those described for the chemical pesticides on this crop. However, the application of crude extracts of virus-infected larvae onto crops such as tomato, which appear to act as build-up hosts for *H armigera* early in each season, would appear to be a technique that would be well worth investigating for use by the farmer or at the village level. Fears of health hazards, which may *or* may not have any factual basis, are likely to persuade national authorities that such a development should not be encouraged. There is a need for basic research to clarify the risks and benefits of this and other potential elements.

The Future of Integrated Pest Management

It is probable that the current shortage of pulses and the consequent high prices offered to farmers for these crops will lead to an increasing interest in pesticide use on pigeonpea, in spite of the difficulties we have described. Equally, however, an explosion of pesticide use on this crop is unlikely, and it is probable that for the foreseeable future, the majority of farmers will continue to grow pigeonpea with few or no purchased inputs.

Groups such as the All India Coordinated Pulse Improvement Project (AICPIP) entomologists, under the leadership of H. P. Saxena, are building up a store of data and knowledge that should soon be sufficient for the setting up of operational research projects in pest management in farmers' fields. The ICRISAT entomologists are pleased to be accepted as supplements to the AICPIP group and enjoy active cooperation with the national pulse entomologists in many parts of India. Initially it would appear to be easierto set up projects that incorporate pesticide use, for these are likely to generate obvious, if not spectacular, yield increases. There would appear to be good prospects for setting up village-level projects using such inputs in the next few years.

The real problem is how to help the great mass of pigeonpea farmers, including the majority who sow intercrops, who are unlikely to benefit from pesticide use in the near future. Elements of pest management other than pesticide use are unlikely to give easily visible benefits. The use of improved cultivars that will give better yields in the farmers' fields would appear to offer the best initial opportunity. Our efforts in augmenting natural control or introducing biological control to this crop are still very much in the preliminary investigatory stages. Our studies of the effects of agronomic and cultural practices on pests have been disappointingly negative. We now know that closer spacing tends to give greater pest problems and surprisingly, that at least one intercrop combination (with sorghum) tends to result in greater losses to pests than those encountered in sole crops (Bhatnagar and Davies 1981).

Thegreatestpotential — and challenge— for the future would appear to lie in a real integrated approach to the *Heliothis* problem, with a consideration of this pest not just on pigeonpea, but on all of its hosts, throughout each year and across large areas. It is hoped that ICRISAT will be able to cooperate in this with other international and national agencies.

Acknowledgment

This work was initiated by Dr. J. C. Davies in 1975 and we acknowledge the firm foundation that he provided. We have a fine team of enthusiastic workers, too numerous to mention individually, but we wish to ensure that their contribution is not overlooked. We are also grateful to the many scientists in many countries, but particularly those in the All India Coordinated Pulse Improvement Project, whose helpful cooperation provides us with valuable data and experience.

References

ANONYMOUS. 1977. Insect control in the People's Republic of China. CSCPRC Report No. 2, National Academy of Sciences, Washington DC, USA. 218 pp.

BHATNAGAR, V. S., and DAVIES, J. C. 1979. Pest management in intercrop subsistence farming. Presented at the International Workshop on Intercropping. ICRISAT, 10-13 Jan 1979, Hyderabad, India. Proceedings in preparation.

BHATNAGAR, V. S., and DAVIES, J. C. 1981. A report on entomological studies in intercropped pigeonpea systems at ICRISAT Center and future developments. Entomology, Volume 2, these Proceedings.

BINORA, O. S. 1968. Insect pests of pulse crops. Indian Farming 17(11): 12-14.

COAKER, T. H. 1959. Investigation on *Heliothis armigera* in Uganda. Bulletin of Entomological Research 50: 487-506.

DAVIES, J. C., and LATEEF, S. S. 1975. Insect pests of chickpea and pigeonpea in India and prospects for control. Pages 319-331 *in* Proceedings, International Workshop on Grain Legumes, 13-16 Jan, 1975, ICRISAT, Hyderabad, India. Available from ICRISAT, Patancheru 502 324, AP, India.

LATEEF, S. S., and REED, W. 1981. Development of a methodology for open field screening for insect pest resistance in pigeonpea. Entomology, Volume 2, these Proceedings.

MATTHEWS, G. A. 1979. Pesticide application methods. London and New York: Longmans. 334 pp.

SHELDRAKE, A. R., NARAYANAN, A., and VENKATARATNAM, N. 1979. The effects of flower *removai* on the seed yield of pigeonpea (*Cajanus cajan*). Annals of Applied Biology 91: 383-390.

Alternative Approaches to *Heliothis* Management

P. Blood*

Abstract

Heliothis, *a serious agricultural pest worldwide, is examined in the context of the pigeonpea ecosystem, with particular emphasis on the approaches available for its control. The technological approaches include behavioral, genetic, varietal, biological, microbial, cultural, and insecticidal control as components of integrated pest management systems. These approaches are surveyed and evaluated with reference to the pigeonpea ecosystem.*

The methodology of control is examined in broad terms, and the components of monitoring, forecasting, modeling, and implementation are placed in perspective. Broad suggestions are offered for research priorities during the next decade.

The *Heliothis* complex is a major — perhaps the most serious — agricultural pest worldwide. In the USA, where statistics on crop losses are reliably recorded, *Heliothis zea* and *H. virescens* are reputed to cause the greatest crop loss (Knipling, personal communication). The U.S. situation projected on a worldwide basis would reinforce the statements above, and abundant — though less reliable — crop-loss data from some developing countries indicate losses of a similar order.

Implicit in the title of this paper is the suggestion that a conventional means of *Heliothis* management exists. Although insecticidal control fills this role in developed countries, the situation is less formalized in developing countries, where reliance has been placed on more natural approaches related to cropping patterns and associated agronomic practices. The contents of this paper will be biased away from conventional insecticidal control approaches but will include the minimum amount necessary to describe a total systems approach. *Heliothis* management should be predicated on comprehensiveness, not exclusivity.

As this conference has been designed to discuss and review research progress in pigeonpeas and, more importantly, indicate profitable directions for future *research, this* paper will concentrate on management systems relevant to the cropping and economic milieus in which pigeonpeas are embedded. The suggestions proposed for pigeonpea/ *Heliothis* management are based on experience with parallel or similar cropping systems. The author will thus address the more prescriptive aspects of systems-building but will avoid concentrating on more esoteric approaches that probably will not leave the drawing-board this decade, if ever.

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The Context of the Agroecosystem

Heliothis-induced crop loss takes place within the context of the agroecosystem and must be studied and controlled within this framework.

The agroecosystem is a complex and dynamic ecological structure that owes its viability to man's intervention. This viability is, in essence, a quasi-stability that quickly disintegrates if man's interventional input of resources, material, or management is interrupted, is inadequate, or of suboptimal mix. Thus the socioeconomic component of the agroecosystem is crucial if the broad objective of profit maximization is *to* be achieved.

Although the agroecosystem is depauperate in terms of major plant species, there are sufficient weeds, nontarget crops, and peripheral nontarget plant speciesto add a level of complexity that precludes too simple an approach to management of the insect and pathogen complex associated with the target crop. The complexity of the problem is exacerbated by physical factors such as meteorological variables and economic factors such as fluctuations in costs and prices. *Heliothis* itself is a major source of complexity and a further barrier to our elucidation of agroecosystem dynamics. *Heliothis* has an immensely wide host range, formidable powers of dispersal, a rapidly deployable genetic constitution, a powerful digestive system, and *an* insatiableappetite for the more marketable components of target crops.

The target crop, pigeonpea, is in itself a complex organism possessing a varying level of determinacy, depending on cultivar. Pigeonpea is also sensitive to agronomic variables of planting density and planting date. Although much has been achieved in relating leaf and bud loss to physiological yield reduction, a multifactor loss/yield response surface model is yet to be completed. Pigeonpea is often a component in multiple- and mixed-cropping situations, which further adds to the complexity inherent in the total pigeonpea agroecosystem.

In attempting to manage *Heliothis* attacking pigeonpea, one must attempt to manipulate the pigeonpea agroecosystem. Here there are two broad philosophies that find currency, one entomological, the other agronomic in approach. Theformer approach seeksto directly eliminate or reduce *the Heliothis* population either locally or on a regional basis. The latter approach seeks an accommodation with *Heliothis* through host nonpreference, avoidance, or tactical, temporary reduction below economic injury levels. These approaches are not mutually exclusive but the former approach is more properly the responsibility of governmental or regional cooperative agencies rather than the individual farmer.

Heliothis management can also be categorized on strategic and tactical bases, but if the technology of control can be surveyed and evaluated, then the methodology of employing this technology and implementing an effective program may be examined in some perspective. This examination will also deal with decision-making machinery, including forecasting.

Technology of *Heliothis* Control

Only those approaches offering substantial potential will be covered in this paper.

Behavioral Control

Insect pheromones have been employed in trapping as a basis for population census and forecasting but more interest has been generated in their role as attractants to kill-traps and, as agents of mating disruption.

Heliothis pheromones are long-chain unsaturated aldehydesthat are unstableto lightand air and therefore require protection in some form or other. The mating-disruption approach in *Heliothis* suppression has attracted considerable attention in the U.S. (Plimmer et al. 1980) in the wake of the gypsy moth program. There will be difficulties in formulating an effective scheme against *Heliothis,* as the gypsy moth program revealed the problems of maintaining effective checks and experimental controls. Formulations currently being developed for widespread application include:

1. Hollow polymeric fibers for ground or aerial application.
2. Three-layered laminated polymeric dispensers for deployment on a terrestrial grid or for use as "flakes" for aerial spray application.
3. Microcapsulesforaerial spray application.
4. "Ropes" or "fences" of polymer containing pheromone.

Results to date in cotton suggest considerable promise and a consensus of experts indicates commercial-scale exploitation of this approach within 10 years.

Attention is also being focused on competitive pheromone inhibitors. These chemicals block the action of the natural pheromones and disrupt the action of the insect's pheromone communication systems.

Whether this approach will have relevance to pigeonpea systems will depend on the effectiveness of future formulations, the economics of application, and the resilience of *Heliothis* in combating this threat to its life system.

Genetic Control

The approaches to genetic control are numerous. The sterile insect release method (SIRM) has received most attention in the past, notably through the screw-worm program, but certain qualifications have to be imposed with reference to *Heliothis.* The proposed use of chemosterilants has died a natural, and foreseeable, death because of health and environmental hazards, and the currently employed radiation-induced sterilization is expensive and fraught with uncertainties in situations other than geographical or ecological "islands."

More sophisticated manipulation using conditional lethals, etc., is showing considerable potential in the family Muscidae but somewhat less for the Lepidoptera.

Perhaps of more note is taster's (1977) work with inherited male sterility in hybrid *H. virescens* and *H. subflexa* in Mississippi. Laster found that when *subflexa* females and *virescens* males were confined together, mating occurred and fertile eggs were produced. Male progeny from these matings were sterile and female progeny fertile. The sterile condition persisted through 78 backcrossings of the female hybrid to male *virescens.*

Laster predicted by means of a number of population models that a natural *virescens* population would be eliminated by the fifth generation if the backcross moths were released in a 30: 1 ratio. If the ratio was reduced to 19:1 or 9:1, local extinction would take 9 and 19 generations, respectively. Laster went on to show that such a release program, if applied to the Delta area of the Mississippi, would cost only 7% as much as a comparable insecticidal program.

Theoretically, this approach has much potential, but a great deal remains to be researched as regards the problems of immigration from non-target areas and the probability of introducing the same or similar genetic mechanisms into *H. armigera.* More realistic cost-benefit analyses also need to be performed in a variety of differing situations.

Varietal Control

Whereas behavioral and genetic control are classified as strictly Type I strategies, i.e., aimed at large-scale reduction of *Heliothis* populations, varietal control is quintessentially a Type II strategy, which may engender Type I impacts, depending on the intensity and comprehensiveness of the program.

Varietal control is an immense subject, but three main components comprise this approach: nonpreference, antibiosis, and tolerance. A fourth, avoidance, may be cross-classified as cultural or agronomic control. The latter two classifications are strictly Type II, i.e., they have only a marginal impact on *Heliothis* populations unless, in the case of avoidance, the varieties exhibiting this character are used regionwide and there are no alternative hosts.

Breeding for *Heliothis* resistance has only been truly active during the last decade, especially the last half-decade, and has assumed different approaches corresponding to the different germplasms involved in the many crops affected by *Heliothis.*

There are two threads common to maize, cotton, and soybean programs: the selection of morphological characters on the one hand and chemical factors on the other. No doubt this dichotomy in resistance breeding would apply to most crops, including pigeonpea. Chemical defence factors tend to be antibiotic in effect, while morphological characters are generally associated with nonpreference. The importance of the above dichotomy lies in the trade-off between the two. Morphological characters are either monogenic or oligogenic and are relatively easy to select and incorporate into acceptable background germplasms, whereas chemical factors are usually polygenic and are associated with more difficult, protracted breeding programs. On the other hand, morphological characters result in only modest levels of resistance, generally below 50% and usually around 20% or less. Chemical factors may result in 100% resistance, i.e., immunity, but levels are usually above 50%.

The choice of a specific resistance factor to be used in a breeding program will be based on the ease of selection and incorporation of each factor and the type of pest management program opted for, e.g., Type I or II. Broad-based programs utilizing multilateral approaches usually require only marginal increments in resistance to achieve economic control and thus must be considered as prime candidates for low-grade resistance breeding programs (Maxwell and Jennings 1980).

Pigeonpea-breeding programs are being intensively pursued, and it would appear that *Atylosia-pigeonpea* hybrids have much to offer in antibiosis and nonpreference to *Heliothis.*

This Workshop will no doubt reveal recent trends in pest-avoidance research with early, medium, late and determinate and indeterminate cultivars in unsprayed trials conducted by AICPIP and ICRISAT.

The use of pest avoidance in breeding strategy is highly complex, as the total agronomic pattern of crop production may be radically altered. The implications are far-reaching, as avoidance strategies require the use of different varieties and/or alteration of planting and harvesting dates. Fertilizer use, pathogen-crop relationships, irrigation use, mixed cropping relationships, and labor and management patterns will all be affected. In fact, the total energy budget will be modified, and this may well result in economic benefits to the farmer above and beyond those solely associated with pest control.

Biocontrol

Other than modifying and reducing insecticidal regimes, the main thrust in developing pest management programs has been through the enhancement of biocontrol.

Biocontrol is central to most entomologists' pest management programs because of the spectacular successes that have been achieved in the past and because it provides the entomologist with an opportunity to employ his specialist training.

It is this writer's contention, however, that biocontrol in its current form of practice is overrated. Biocontrol has relied almost exclusively on the classical approach of introducing natural enemies from areas located within or around the center of origin of the pest. The low percentage of cases that have been successful have been spectacularly so (Huffaker and Messenger 1976), but if this percentage were to be graphed against the last 15 years and projected forward in time, it would be found that a negative exponential curve would apply. It seems clear that the potential for future success will be predicated on more vigorous exploration and/or prerelease selections and breeding of biocontrol agents to better fit a specific situation.

In attempting a biocontrol effectiveness evaluation, it is important to define objectives. If a Type I objective is desired, introduction of one or more agents may lead to a lower "equilibrium" expectation, but this will neither be predictable in space nor in time. As a management option, this approach leaves much to be desired.

Additionally, *most Heliothis* parasitoids act at the larval or pupal stage, which means that considerable damage by earlier instars is not prevented, and a parasitoidism rate of more than 50% is difficult to achieve in nonaugmented situations. Introduction of predators has not found favor in most programs as their polyphagous nature renders them unpredictable and ineffective in most managed situations.

Individual survival probability increases as each stage approaches maturity, i.e., an egg, for example, has less probability of reaching adult stage than does a pupa, even though stage mortality may be identical in each case. Basing tactics on this premise would lead to mortality being directed to later stages. However, later stages consume greater proportions of plant tissue than do earlier stages, necessitating mortality to be effected in earlier stages. The optimal "killing stage" is obviously a trade-off between natural mortality probability of each stage, potential biomass consumption of each stage, and the effectiveness, on a cost-benefit basis, and predictability of the biocontrol agent.

This logic would suggest that some biocontrol agents would lend themselves to a Type I situation, which, as indicated earlier, may not be effective, while others may lead to Type II situations, which again may be ineffective in themselves in preventing economic damage but may form a significant component in a total management package.

Another major disadvantage in the exotic introduction approach to biocontrol lies in the preferences exhibited by many beneficial insects to certain plant species. This has led to the selection of crop-adapted strains of *Trichogramma* in the USSR (Ridgway and Vinson 1977).

This principle is also strikingly illustrated in the sorghum/pigeonpea intercrop in south India. *H. armigera* is parasitoidized by hymenopterans and dipterans in the sorghum and pigeonpea components, respectively, corresponding to their flowering periods. There is no transfer of agents from one crop to the other, even though the two crops exist within an intimate intercrop situation (ICRISAT Annual Reports).

The alternative to the introduction approach is the use of augmentation. There are many disadvantages inherent in this approach: economy of operation is only possible through the use of inexpensive labor; technological or engineering breakthroughs are necessary to promote the approach in developed countries; augmentation, unlike the introduction approach, is a continuous operation of breeding and release rather than a single release program; as a management tactic, augmentation must be correctly timed and the numbers released must conform to the principle of the minimum effective density — a task requiring some degree of expertise.

Augmentation biocontrol is strictly a Type II strategy, and although the approach suffers from the disadvantages outlined above, the advantages may be considerable: (1) Augmentation is demonstrably more economic than insecticidal approaches in developing countries (Ridgway and Vinson 1977). (2) There are indirect benefits derived from the avoidance of insecticide-induced problems. (3) This approach is far more predictable and quantifiable than the introduction approach. (4) The egg stage of *Heliothis* can be targeted by egg parasites and, if necessary, the early larval stages subsequently. (5) Automation and technological breakthroughs should allow low-cost mass production of beneficials in developed countries in the short to medium term.

Another approach similar to augmentation is the use of applied food medium to augment beneficials already present within the crop system. The advantages in this approach are that the application of food medium is less complicated than breeding and releasing insects and, in addition, the beneficials within the crop system are already preadapted to the specific environment. But this approach will probably not find application in the short term.

Microbial Control

This approach parallels the classical biocontrol approach in that an exotic pathogen may be imported and then become established in the target country's microflora *or* microfauna, leading to a new pest density equilibrium. Alternatively, pathogens may be manufactured, formulated, and applied like insecticides and act in much the same way, i.e., as a direct crop protectant.

Microbial control of *Heliothis* is an.established fact in the applied sense in that manufactured microbials such as *Baculovirus heliothis,* the nuclear polyhedrosis virus *of Heliothis,* and *Bacillus thuringiensis* are routinely employed against *Heliothis* in many crop systems, especially cotton. In a nonapplied sense, a numberof epizootics occur, caused by a variety of microorganisms that must lead to a general decline in *Heliothis* population equilibrium. The organisms responsible for these epizootics may be bacteria, viruses, fungi, e.g. *Nomuraea rileyi;* protozoa, e.g., *Nosema heliotidis;* nematodes, e.g., *Neoaplectana carpocapsae.* No doubt rickettsia-like and mycoplasma-like organisms will be implicated in low-grade *Heliothis* infections.

The main disadvantages with the microbials, excluding those commercially manufactured, lie in their cost, their unpredictable nature, their reliance on environmental conditions conducive to disease initiation, and their effectiveness only late in the life cycle of the pest, well after economic damage has resulted.

The commercial exploitation of microbials is still in its infancy, however, and their very great advantages, including their nonimpact on insect beneficials, assure an important future role for them in comprehensive pest management programs. Future prospects seem to be tied to effective, inexpensive mass production of candidate microbials (Weiser et al. 1976).

Cultural or Agronomic Control

The employment of modifications of general cultural and farming practices to better control insects has been regarded as a useful adjunct to mainstream pest control ever sinee the practice of the crop protection began.

Relegation of this approach to an "adjunct" has, in this author's opinion, been counterproductive in that any agronomic adjustments to the cropping systems have to satisfy many objectives in addition to that of insect pest control. Crop protection issues may not have received adequate attention in agronomic planning, but by the same token, undue emphasis on one aspect of crop production, such as protection, will lead to imbalance and inefficiency of the total cropping system. The rationale of dealing with factors of cultural control and incorporating them in a multiobjective systems design will be discussed in the modeling subsection of this paper.

Cultural control may be exercised through a plethora of options and combination of options: sowing dates or harvesting dates may be changed; irrigation schedules and regimes modifed; fertilization rates adjusted; and various cultivation regimes employed, both pre- and post-sowing — planting densities, planting pattern, e.g., double rows, skip rows, or narrow rows, strip-cropping, intercropping, trap-cropping, and multiple-cropping.

It is virtually impossible to proffer ex-ante recommendations or guidelines on the type or combination of cultural controls acceptablefor a given crop situation; each system needs to be treated individually in each locality, and possibly each season.

In the U.S., *H. zea* damage in soybeans is reduced by narrow-row planting, which aids in closing-in of the plant canopy before blossoming begins. *H. zea* is not attracted to soybean as an oviposition site except during the flowering period. Additionally, the closing-in of the soybean canopy induces an environment favorable for the development of *Nomuraea epizootics,* also reinforcing *Heliothis* control (Newsom et al. 1980).

In experiments in Texas, the use of a short-season cultivar low-input package in cotton production resulted in dramatic changes in costs, yields, profit, and pesticide inputs (Sprott et al. 1976). The short-season system required only 20 to 30% of the fertilizer application of the conventional system, 60 to 70% of irrigation, and 40 to 70% of the pesticide. Although costs on *an* acreage basis were similar, costs per pound produced were only 67% of the conventional.

Likewise, energy expenditure of the short-season system was only 67% of that of the conventional system. Thus profit from the short-season cotton was 2.74 times higher with normal row width and four times higher with narrow rows than net profit from the conventional system.

Insecticidal Control

Controlling *Heliothis* through the use of insecticides is currently the most popular, if not the most preferable, method. Although not strictly an "alternative" approach to *Heliothis* management, insecticidal control may nevertheless constitute a key component in a rational, integrated pest management program.

The major disadvantages for the grower who relies on insecticides have been the short-term loss of beneficials and the medium-term risk of efficacy loss through insecticide resistance buildup. Selective and accurate application of insecticides will ameliorate, if not remove, these problems. Chemicals that are "soft" on beneficials are available, and if insecticide-induced mortality of *Heliothis* is but a small proportion of total mortality, then the normal selection pressures generated by unilateral pesticide-based programs will not become evident in the rapid rise of resistant *Heliothis* populations.

Research carried out mainly on *Heliothis* in cotton has indicated that compounds such as endosulfan, chlordimeform, amitraz, and methomyl (ovicidal rates) tend to allow for some persistence of beneficials within the system.

Compounds still in the experimental stage in the U.S. but slated to become available for *Heliothis* control shortly are AC 222, 705; carbofuran; cypermethrin; profenis CGA-15324; Quinalphos; Rohm & Haas 218; thiodicarb; Zoecon ZR-3210 (USDA 1980). Unfortunately, these compounds have little to offer with respect to pest management. The preferred compounds against *Heliothis* in cotton systems seem to rest on the synthetic pyrethroids, notably fenvalerate, permethrin, and decamethrin (NRDC 161 Decis). These compounds are highly effective, but they are nonselective and extremely expensive *to* use. No documented confirmations of resistance to these compounds are currently reported, but numerous personal communications within the U.S. pesticide industry suggest that *Heliothis* resistance to these compounds is an established fact.

It is unlikely that a single compound can be synthesized to fit all the specifications of a prescribed pest management program; therefore, the search should be for multilateral systems.

The Methodology of Pest Management

Thus far, discussion has covered the various technological approaches available for *Heliothis* control. We will now examine such managerial decisions as what approach(es) to use, in what quantities, what sequence, at what rate, time, and frequency, and in what combination.

These decisions fall naturally into three major categories; monitoring/sampling, modeling, and implementation.

Monitoring-Sampling

Decision-making with respect to *Heliothis* depends on accurate estimations of its presence in the target crop and forecasts of its likely presence during future periods of the crop. Thiscan only be achieved by monitoring the crop throughout its phenology, using an appropriate sampling program for *Heliothis.* Logically, this sampling should be done in the proper context; thus the crop's physiological status, including damage; meteorological variables such as precipitation and temperature; predators and parasitoids of *Heliothis;* and other variables also need to be sampled.

Sampling applies both to the immature stages (eggs and larvae) and the adults. Sampling of immatures is time-consuming and becomes a formidable task if large areas are to be monitored. Sequential sampling offers considerable savings. Adult sampling of *Heliothis* is favored in that adult monitoring can serve as indexes to subsequent stages — eggs and larvae — and can therefore anticipate crop damage. Trap catches are relatively easy to service and provide a sampling coverage up to hundreds of hectares, depending on trap-type, crop, and terrain. In addition, each trap can form a component in a multitrap regional grid providing large-scale comprehensive prediction service as well as a population migration research tool.

The most authoritative information on adult *Heliothis* sampling is that of Hartstack et al. (1979) who have provided the main impetus in this direction. These workers surveyed the role of light traps using different light sources and structural designs, and compared their advantages with those of pheromone traps. The authors routinely use a simulation program (MOTH 2V-2), which projects an age distribution of *Heliothis* throughout the remainder of the season. To date, this program has proven to be qualitatively efficient, i.e., it predicts outbreak dates quite accurately; however, in quantitative terms, the program needs extensive modification (Hartstack, personal communication). The main feature of this program is its ability to direct in-field samplings and scouting in accordance with short-term (1 week) forecasts.

Forecasting

This subject may more properly fall under the heading of modeling but it may be useful to comment on its applications. MOTH ZV-2 is based on the physiological time concept and therefore on accurate meteorological forecasts of maximum and minimum daily temperatures for the forecast period. Unfortunately, the reliability of such forecasts is limited to some 4 days in the southern U.S. and to a shorter period in the summer-rainfall areas of Australia. It is possiblethat predictability of daily temperature is much higher in tropical India, especially at higher altitudes.

Forecasting is a complex mathematical operation involving a variety of approaches. Synoptic weather charts are used as input to multiple regression-based statistical programs. Meteorological data for a specific location can be averaged over many years, and this may prove a useful basis for pattern identification (Lowry 1970).

Any simulation program designed for forecasting will only be as efficient as the weather forecasts used as input. It seems certain that historical weather data for a specific locality, synoptic weather data, and comprehensive regression analyses within a subjective or a Bayesian framework should prove more adequate in providing a "rolling horizon" for prediction purposes.

Provided that sufficient and detailed historical data on *Heliothis* population dynamics are available for a specific locality, it may be possible to introduce powerful techniques of forecasting such as the Box-Jenkins time-series analysis (Nelson 1973). However, such sophisticated approaches will not be generally available until perhaps the end of this decade.

Modeling

The decision-making prerequisites referred to earlier may be supplied by modeling. The two major objectives of modeling are to determine the technological mix of controls and thetiming and quantities of the controls in a globally optimal sense. There are other less important objectives related to such issues as determining research priorities. Sensitivity analysis is only possible through the medium of a model.

Integrated Control

Before the term "integrated pest management" was coined, "integrated control" was widely used. Implicit in this term was the notion that integration was somehow advantageous (somewhat in line with the "diversity leads to stability" hypothesis). Unfortunately, no attempt has been made to quantify this notion or to provide a mathematical basis to the concept in the literature.

Operations research, however, provides the optimizing tool known as linear programming (LP), a variant of mathematical programming. LP seeks to maximize an objective composed of a number of variables together with their coefficients, subject to a vector of constraints being imposed. Thus in a pest management context the LP formulation may assume a variety of structures. For example, the objective may be the maximization of crop yield, subject to budgetary constraints on each of the control alternatives. On the other hand, the objective may be the minimization of cumulative *Heliothis* population levels, subject to legislative, budgetary, and subjective constraints imposed on the combinational limits of the mix of controls.

There are considerable difficulties in formulating realistic LP structures, due mainly to the paucity of data on basic agronomic relationships. But the machinery does exist to optimize the integration mechanism in *astatic* sense (Pfaffenberger and Walker 1976).

Economic Thresholds

The economic threshold and economic injury level have become an accepted fixture in pest management literature. The concept that a certain number of pests in a prescribed area of crop should trigger control operations or cause economic damage is attractive. The reality, unfortunately, is distant from this notion. It is true that there will be a specific pest density level that warrants action, but the complexity inherent in prescriptive decision-making goes far beyond the simplistic recipes advocated by most practicing entomologists.

There are three main barriers to the optimization of pest management.

GOAL CONFLICT. The objective of profit maximization is central to most growers, but other valid goals may be recognized as either private or societal objectives; e.g., the minimization of pesticide hazards.

Provided that these major goals can be reconciled and some quantifiable compromise reached, the technique known as multiobjective programming (Cohon and Marks 1975) may be employed to advantage.

RISK AND UNCERTAINTY. Nature is stochastic, and pest management operates in an environment of risk and uncertainty.

There are six sources of risk:

- Economic: short- and long-term changes in costs and prices.
- Physical: short- and long-term fluctuations in temperature, rainfall, radiation, etc.
- Biological: unanticipated invasions of pests, diseases, and weeds; uncertainty associated with performance characteristics of specific crop- cultivar-environment combinations.
- Entrepreneurial: age, experience, and expertise of the grower and his advisers and the psychology of their decision-making.
- Political: government intervention in price and income supports, etc.
- Technological: a progressive shift into methodology and technology untested by experience.

Risk (where the probabilities of alternative events are known) and uncertainty (where the events, but not the probabilities, are known) have to be either reduced or captured within the decision-making apparatus. The objective is to convert uncertainty to risk by means of forecasting and then capture the risk in a form of stochastic programming (Anderson 1976). Although the machinery exists that can solve this problem, there will need to be some trade-off between expensive stochastic programs and their deterministic equivalents that will be less expensive in terms of computer time.

INTERTEMPORAL DECISION-MAKING. Perhaps the most difficult problem in pest management decision-making is the formulation of a program that allows individual control decisions through the season to conform to constraints of both local and global optimization rules.

Current practice relies on treating separately each decision period throughout the season and each decision presumably being optimal for each period. In retrospect, however, what results is a series of "best at that time" decisions, which, in totality, do not constitute a globally optimal sequence.

Dynamic programming, or DP (Shoemaker 1976), allows for solution of this problem, but thistechniquecannot cope with a multivariable, multiprobability environment and multistage decision process. Currently, the only way to employ DP in realistic decision-making for pest management is to "collapse" the system and use DP analyses as policy guidelines.

The alternative is to sacrifice global optimality and use an optimizing tool such as recursive programming (RP), which does not suffer from problems of dimensionality (Day 1963).

Implementation

The end result of monitoring, modeling, and decision-making is implementation and there seem to be two basic ways in which implementation can be effected:

Sequential Sampling

Sequential sampling derives from quality or reliability control theory and makes use of three informational inputs: spatial distribution of target organisms; treatment, no treatment, and "keep sampling" thresholds; Type I and II error levels, i.e., deciding to treat when not justified anddeciding not to treat when in fact, treatment can be justified. Given that the three inputs are realistic, then decision-making can be made rapid yet accurate. Scouts monitoring a crop and pest system can make these decisions duringtheirsampling, i.e.,the sampling, modeling, and implementation phases are integrated into the same operation.

Sequential sampling plans have been constructed for *Heliothis* on many crops throughout the world, and considerable savings in time, money, and pesticide load have resulted (Sterling 1977). The disadvantages associated with this approach are that inputs such as treatment thresholds and Type I and Type II errors are still in their formative stages. Type I and II errors are usually set at predetermined and subjective levels instead of constituting variable outputs of a model involving crop and grower psychology parameters. The economic or treatment thresholds currently used in sequential sampling plans are, at worst, educated guesses, and at best, the results of ad hoc trials.

On-line Management

Simulations describing crop growth and insect pest dynamics have been constructed and allow for sensitivity analysis. Theoretically, it should be possible to determine optimal pathways through the use of response surface methodology; however, attempts at the University of Queensland have so far proved unsuccessful, for technical reasons. Optimization of simulation models will probably require linkage with mathematical programs, thus resulting in hybrid models. The thrust in pest management is towards the use of "on-line" pest management (Tummala 1976). This concept involves the use of a forecasting device linked to a crop and pest model, which in turn is linked to an optimization routine. Fields are monitored by scouts, and this information is electronically communicated to the central or local computer. The models are run, and the output is then relayed to extension officers who interpret the results to the grower, who is then free to act upon this advice. Such a system, run by Purdue University, has been operating for lucerne and the alfalfa weevil in Indiana, USA (Peart and Barrett 1976).

It is evident that this approach is more sensitive to the vagaries of the environment and has a more powerful infrastructure than sequential sampling. The only disadvantage isthe expense and difficulty of maintaining a communications network.

The Pigeonpea Ecosystem

As indicated in the Pulse Entomology (Pigeonpea) 1978 Report, AICPIP policy trends areto discontinue the use of DDT on pigeonpea, resulting in the use of expensive alternatives if unilateral insecticidal programs are to be relied on. According to the report, the cost-benefit figuresforpigeonpea production will allow only one profitable spray application. The implications are very clear: the decision to spray is critical, and the impetus for seeking alternative controls is strong.

It is the author's contention that the pigeonpea ecosystem resembles a semideterminate, short-season cotton ecosystem in many aspects. Short-season cotton tends to escape late-season *Heliothis* attack and yields about 65% of the long-season irrigated equivalent. However, if theearly part of theseason has been drier than usual, and *Heliothis* pressure lower than normal, the grower may opt to allow his semideterminate cultivars to utilize abnormally high mid-seas on rainfall to speculate on a larger but risky late crop.

The monsoonal influence assures the Indian grower of less risk, but the number of strategies available appear to be endless, especially when intercropping is taken into account. The number of tactics is limited, however, as it would appear that unaugmented classical biocontrol is inefficient, insecticidal control is unwarranted on account of its expense, and cultural and varietal control require a great deal more research to make useful contributions. With regard to tactical decision-making, there must be a switch away from heuristic systems toward more holistic programs (Blood 1980). Such programs need not be complicated and therefore unacceptable to the pigeonpea g rower. If a monitoring network can be established, backed by a modeling group, e.g., under the auspices of AICPIP, then implementation may be effected through extension personnel, backed up by a village radio.

Conclusions

Successful *Heliothis* management in the pigeonpea system will depend very much on the level of sophistication deemed justifiable, given pigeonpea losses and the quantity of funds procurable for pigeonpea research.

It would appear from the Indian pigeonpea literature in general and the ICRISAT pulse entomology and cropping entomology reports in particular that pertinent research in pigeonpea protection and*Heliothis* dynamics is very active.

The decision to establish *Heliothis* control on a network basis, i.e., a Type I approach, is a matter for workers in AICPIP and for the administrators to consider. A Type I approach is now being employed against the boll weevil in the U.S., but at great expense. Naturally, if it is successful, the rewards will be immense.

The decision to opt for an "on-line" management system can also prove expensive, but again the rewards will be inestimable if but one insecticidal spray can be prevented.

These decisions are dificult to make, but it is the author's opinion that the benefits so outweigh the costs that only one decision is possible.

References

ANDERSON, J. R. 1976. Essential probabilities in modeling. Agricultural Systems 1: 219-231.

BLOOD, P. R. B. 1980. Ecological and economic guidelines in the management of tropical agroecosystems. Presented at the Fifth International Symposium on Tropical Ecology 1979, Kuala Lumpur, Malaysia.

COHON, J. L, and MARKS, D. H. 1975. A review and evaluation of multiobjective programming techniques. Water Resources Research 11: 208-220.

DAY, R. H. 1963. Recursive programming and production response. Amsterdam, The Netherlands: North Holland.

HARTSTACK, A. W., HENDRICKS, D. E., LOPEZ, J. D., STADELBACHER, E. A., PHILLIPS, J. R., and WITZ, J. A. 1979. Adult sampling. Pages 105-131 *in* Economic thresholds and sampling of *Heliothis* species on cotton, corn, soybeans, and other host plants. Southern Cooperative Series Bulletin, 231 pp.

HUFFAKER, C. B., and MESSENGER, P. S. eds. 1976. Theory and practice of biological control. London: Academic Press.

* **KOGAN, J., SELL, D. K., STINNER, R. E., BRADLEY, J. R., and KOGAN, M. 1978.** The literature of arthropods associated with soybean. V. A Bibliography of *Heliothis zea* (Boddie) and *H. virescens* (F) (Lepidoptera: Noctuidae). University of Illinois INTSOY Series 17, Champaign-Urbana, Illinois, USA.

LASTER, M. L. 1977. The *Heliothis* hybrid, *H. subflexa* x *H. virescens* as a population suppression measure for the tobacco budworm. Pages 144-147 *in* Proceedings, Beltwide Cotton Producers' Research Conference. 1977, Atlanta, Ga, USA.

LOWRY, W. P. 1970. Weather and life, an introduction to biometeorology. New York: Academic Press.

MAXWELL, F. G., and JENNINGS, P. R., eds. 1980. Breeding plants resistant to insects. New York: Wiley-Interscience.

NELSON, C. R. 1973. Applied time series analysis. San Francisco: Holden-Day.

NEWSOM, L. D., KOGAN, M., MINER, F. D., RABB, R. L., TURNIPSEED, S. C, and WHITCOMB, W. H. 1980. General accomplishments towards better pest control in soybean. *In* New technology of pest control, ed. C. B. Huffaker. New York: Wiley-Interscience.

PEART, R. M., and BARRETT, J. B. 1976. Simulation in crop ecosystems management. Pages 389-402 *in* Proceedings, 1976 Winter Simulation Conference, eds. H. J. Highland, T. J. Schriber, and R. G. Sargent.

PFAFFENBERGER, R. C, and WALKER, D. A. 1976. Mathematical programming for economics and business. Ames, Iowa, USA: Iowa State University Press.

PLIMMER, J. R., LEONHARDT, B. A., SPARKS, A. N., PRINIANI, M., and CHAPMAN, O. L. 1980. Sex pheromone components of *Heliothis zea* and *H. virescens.* Presented at the Beltwide Cotton Conference. 1980, Dallas, Texas, USA.

RIOGWAY.R. L., and VINSON, S. B., eds. 1977. Biological control by augmentation of natural enemies. New York: Plenum Press.

SHOEMAKER, C. 1976. Insect pest management modelling. Cornell University, Department of Environmental Engineering, Ithaca, NY, USA.

SPROTT, J. M., LACEWELL, R. D., NILES, G. A., WALKER, J. K., and GANNAWAY, J. R. 1976. Agronomic, economic and environment implications of short-season, narrow-row cotton production. Texas Agricultural Experiment Station Miscellaneous publication 1250, Texas, USA.

STERLING.W.L. 1977. Sequential decision plans for the management of cotton arthropods in south-east Queensland. Australian Journal of Ecology 1: 265-274.

TUMMALA, R. L. 1976. Concept of on-line pest management. Pages 28-31 *in* Modelling for pest management, eds. R. L. Tummala, D. L. Haynes, and B. A. Croft. East Lansing, Mich, USA: Michigan State University Press.

USDA (United States Department of Agriculture). 1980. 33rd Annual conference report on cotton-insect research and control, St. Louis, Missouri. Availablefrom USDA, P.O. Box 53326, New Orleans, La, USA.

WEISER, J., BUCHER,G. E.,and POINER, G. 0.1976. Host relationships and utility of pathogens. Pages 169-186 *in* Theory and practice of biological control, eds. C. B. Huffaker and P. S. Messenger. London: Academic Press.

* Kogan et al. is the most comprehensive work published on *Heliothis zea* and *H. virescens,* with over 5000 citations cross-indexed into some 20 subjects. Most of the applied material is relevant to *H. armigera* and other *Heliothis* species.

Discussion — Session 3

Sehgal:

The pigeonpea crop is attacked by a complex of pod borers. Control of *Heliothis* alone in isolation could result in a vacuum that will soon be filled by other members of the pod-borer complex. Does such a problem exist in Australia?

Blood:

There is always the risk that an ecological vacuum will be filled, but in Australia to date there seems to be no other significant pest or potential pest to compete with *Heliothis* or to fill a vacuum in its absence. *Heliothis* is by far the most important pigeonpea pest in Australia, and, judging from Dr. Reed's talk, in India as well.

C. B. Singh:

What is the nature of resistance against *Heliothis* in *Atylosial* Does the hairy pod surface contribute to nonpreference?

Reed:

We think that a chemical antibiosis is of importance. Hairiness alone has been shown to increase oviposition by *Heliothis* on other crops, including cotton. However, some plant hairs are glandular, and the contents of these may affect oviposition and larval feeding.

Joshi:

Antibiosis is dependable, but has the chemical principle been identified and characterized? What effect does it have? Reduced egg-laying or prolonged larval stage, etc.? Is hairiness a factor in plant resistance to pests? We must be rather cautious in concluding that it is, unless in-depth studies are made. In cotton, breeders have laid great emphasis on hairiness for jassid resistance, but we have demonstrated that it is not very important; in fact, it may encourage other pests.

Reed:

The antibiosis factor in *Atylosia scarabeoides* has not yet been isolated or identified, but it prolongs larval life, reduces weightgain, and reduces the survival of larvae and pupae. We will work on this with the Max Planck Institute, Munich, West Germany.

Chhabra:

Cotton plant residues are destroyed because of the problem with a carryover of pests. Is there any need to destroy pigeonpea plant residues?

Reed:

The clearance of plant residues is more effective on other crops, particularly cotton for pink bollworm control. Clearance of pigeonpea residues may help in disease reduction; there is also a chance that some pigeonpea insect pests, such as podfly, may diapause and be carried over in crop residues. But most pigeonpea crop residues are gathered for fuel anyway.

B. M. Sharma:

The Ministry of Agriculture, Government of India, has taken pest control as a major strategy for increasing pulse production in the country. Budgetary allocation for this item is 17 million rupees; assistance to farmers includes the entire cost of spraying operations, 25% reduction in pesticide costs, and 50% reduction in equipment costs.

Tahiliani:

In middle Gujarat, cotton is being replaced by sole pigeonpea. This subsidy scheme may not be enough to control pod borers on a large scale.

H. P. Saxena:

Dr. Sharma may take note of that. To

conclude this session, I have three comments:

1. The use of insecticides on pigeonpea, though shown to be profitable in experiments, needs to be guided and implemented by extension and development agencies to make it practicable and appropriate.
2. We should endeavor to develop operational research projects — possibly AICPIP and ICRISAT could cooperate productively in testing and selecting pest management elements.
3. We need to develop technology suited to managing pests of early-maturing pigeonpea cultivars the use of which is rapidly increasing in the irrigation command areas of northwestern India.

Session 4

Pathology and Weed Management

Chairman: F. J. Williams

Rapporteurs: M. V. Reddy
J. Kannaiyan

Resistance to Major Pigeonpea Diseases

Y. L. None, J. Kannaiyan, and M. V. Reddy*

Abstract

Wilt (Fusarium udum), *sterility mosaic (virus?) and Phytophthora blight* (Phytophthora drechsleri *f. sp.* cajani) *witches' broom (virus and mycoplasma?), rust* (Uredo cajani), *and leaf spot* (Cercospora cajan) *are some of the important diseases of pigeonpea. Good sources of resistance to wilt, sterility mosaic, Phytophthora blight, and leaf spot are available.*

Pigeonpea *(Cajanus cajan* [L] Millsp.) is cultivated in the Indian subcontinent, southeast Asia, Africa, and Central America. More than 50 diseases have been reported to affect pigeonpea, but fortunately only a few of them are of economic importance. These include wilt *(Fusarium udum* Butler); sterility mosaic (virus?); Phytophthora blight *(Phytophthora drechsleri* Tucker f. sp. *cajani* [Pal, Grewal and Sarbhoy] Kannaiyan et al.); witches' broom (virus and mycoplasma?); rust (*Uredo cajani* Syd); and leaf spot *(Cercospora cajani* Henn.). Wilt is serious in the Indian subcontinent and eastern Africa; sterility mosaic and Phytophthora blight in India; witches' broom and rust in Central America; and Cercospora leaf spot in India and eastern Africa. Several reports on the sources of resistance to wilt (Alam 1931; Anonymous 1950, 1953, 1976; Baldev and Amin 1974; Butler 1908; Dastur 1946; McRae and Shaw 1933, Mundkur 1946; Singh and Mishra 1976; Vaheeduddin 1956) and some reports on Phytophthora blight (Mahendra Pal et al. 1970) and Cercospora leaf spot (Onim and Rubaihayo 1976) have appeared in the literature. In 1974 we intensified research at ICRISAT on the development of efficient screening techniques and on the identification of sources of resistance to three major diseases: wilt, sterility mosaic, and Phytophthora blight. This paper reviews the work on sources of resistance to major diseases of pigeonpea.

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Wilt *(Fusarium udum)*

A large number of papers on highly varied aspects have appeared in the literature since the disease was first described from India by Butler, a British mycologist, in 1906. In 1910 he described in detail pathogenicity experiments and also named the causal fungus as a new species, *Fusarium udum.* Attempts have been made to change the name to *F. oxysporum* f. sp. *udum,* but we agree with Booth (1971) and prefer the name *F. udum.* An attempt to identify wilt-resistant lines was made as early as 1905 at Poona (now Pune) in India (Butler 1908, 1910). The disease is widely prevalent in India (Butler 1906), but is particularly serious in central and northern India. It is serious in Kenya and Malawi and has also been observed or reported from Bangladesh, Mauritius, Ghana, Tanzania, Uganda, Indonesia, Thailand, Grenada, and Trinidad (Nene 1980).

Screening Techniques Adopted

We have standardized two techniques, both involving the use of "sick" soil (Nene et al. 1980b). In the first, soil in pots is made "sick" by incorporating fungus inoculum and then repeatedly growing and incorporating wilted plant debris of a susceptible cultivar. Within 6 months the pots are ready for screening the test material. In the second, the soil in a field is made "sick" by using a similar technique. Plots where pigeonpea wilt has been seen are identified. A susceptible cultivar (homogeneous seed) of pigeonpea is grown, and wilted plants incorporated, for two to three seasons, after which the plots become uniformly "sick" and ready for screening (Nene et al. 1980a, 1980b).

Sources of Resistance

Screening work was initiated in India around the time the disease was described in 1906. Research centers where resistance work was or is being carried out are: Pune (Butler 1910), Pusa (Alam 1931; McRae and Shaw 1933), Delhi (Mundkur 1946; Deshpande et al. 1963; Baldev and Amin 1974); Kanpur (Dey 1948; Singh and Mishra 1976); Parbhani (Raut and Bhombe 1971; Anonymous 1976); Sangareddy near ICRISAT Center (Veheeduddin 1956, 1958); and ICRISAT Center. Several lines have been claimed to be resistant. When we tested many of these, wedid notget uniform resistance. Itis possible that the seed we have in our germplasm collection came from outcrossed plants and therefore many plants show susceptibility. Some of the cultivars that consistently show low disease levels are NP(WR)15, 15-3-3, BDN-1, and 20-1. Another cultivar, NP-80, has been mentioned repeatedly in the literature since 1933 (McRae and Shaw 1933) as being highly resistant; however, we have not been able to obtain authentic seed.

Since it took us some time to develop a good sick plot, we could initiate dependable field screening only in the 1976-77 season. As the first step, we focused our attention on (1) cultivars already claimed to be resistant and (2) lines identified as resistant to sterility mosaic. We have been discarding the susceptible segregants and selfing individual resistant plants to fix wilt resistance in a homozygous condition. We now have some promising lines that came from both types of materials. Systematic screening of germplasm has been initiated, and screening of breeding populations generated by ICRISAT pigeonpea breeders is being carried out. Multilocation testing of promising lines has been initiated in cooperation with the Indian Council of Agricultural Research. Table 1 summarizes the screening work done until April 1980.

Lines that have been found resistant at ICRISAT Center, seed of which is available for testing, are:

ICP-1641	6831	7198	7867	8861	8865
3753	7118	7201	8858	8862	8867
3782	7120	7273	8859	8863	8868
4769	7182	7336	8860	8864	8869
5097					

Banda Palera Sel., AWR-74/15 Sel., Bori-1 Sel., Cross no. 74342, and Cross no. 74363.

It is clear that we do have good sources of resistance to wilt, but multilocation tests (Fig. 1) have shown that lines found resistant at ICRISAT Center are not resistant at all locations, which might indicate existence of races of the fungus. We do have preliminary indications from pot tests that races probably exist, and there is an urgent need to study this aspect of wilt in more detail and intensify multilocation testing.

Sterility Mosaic (Virus?)

The first report on the occurrence of sterility mosaic was published by Mitra (1931) from Pusa in the state of Bihar, India. This was followed by a more detailed description by Alam (1933). Subsequently it was reported from other states of India (Capoor 1952). Capoor established the infectious nature of the disease through graft transmission. He also claimed success in sap inoculation, but this has not yet been confirmed. Later Seth (1962) from New Delhi reported transmission by an eriophyid mite, *Aceria cajani* Channabasavanna. Narayanaswamy and Ramakrishnan (1965) in-

Table 1. Screening for resistance to pigeonpea wilt at ICRISAT Center 1976—1980.

Total germplasm screened	2302
Resistant lines identified[a]	31
Resistant lines tested through multilocation tests	15
Lines resistant at more than one location	14
Breeding materials screened	8173

a. From lines already claimed to be resistant, from sterility-mosaic-resistant lines, and from germplasm.

dicated the possibility of the transmission by nematode; however, this could not be confirmed later. A similar disease has been reported/observed in Burma (Su 1931), Sri Lanka (Newton and Peiris 1953) and Thailand (Nene 1980).

The characteristic symptoms of the disease are reduced growth, bushy and pale appear-

Figure 1. Multilocation testing of disease-resistant lines of pigeonpea (ICAR-ICRISAT cooperative trials) in India.

ance, mild mottle or ringspots on leaflets. The plants may be wholly or partially sterile (Nene 1972).

Screening Techniques Adopted

We have developed two simple and effective procedures for screening by leaf-stapling (Nene and Reddy 1976a) and by spreader rows (Nene et al. 1980b). The leaf-stapling procedure involves collecting leaflets from diseased plants with good populations of the mite vector and then stapling one or two of these leaflets on each of the two primary leaves of the test seedl ings. The virul if erous mites move from the drying leaflets to healthy seedlings and so transmit the causal agent. By 1976, over 2000 germplasm accessions had been screened using this technique, and five resistant lines were identified (Nene and Reddy 1976b). Since the leaf-stapling technique was found to be tedious for large-scale field screenings, we developed the spreader-row technique, which consists of planting rows of a susceptible cultivar 4 to 6 months in advance of the test material. Plants in the spreader rows are inoculated by the leaf-stapling procedure, and the disease is allowed to develop. The mites multiply in large numbers on these rows and are dispersed by the wind, thus spreading the disease to test rows in the normal season. This technique works very effectively. If necessary, the leaf-stapling procedure can be used in the field to supplement the spreader-row procedure to guard against escapes.

Sources of Resistance

Alam (1931) claimed that a selection of the pigeonpea cultivar, Sabour 2E, was resistant to wilt as well as to sterility mosaic. Authentic seed of this cultivar could not be obtained for testing. There were no subsequent reports of work on sources of resistance until Ramakrishnan and Kandaswamy (1972) published their work. They were unable to identify good sources of resistance; however, some cultivars such as NP (WR)-15 were considered tolerant In 1975 we initiated systematic large-scale screening and have identified a fairly large number of resistance sources. The seed of these lines has been maintained and is available for testing. Our progress is summarized in Table 2. A large amount of breeding material with resistance to sterility mosaic is now in the advanced stages of testing.

Table 2. Scrawling for resistance to pigeonpea sterility mosaic at ICRISAT Center 1975-1980.

Total germplasm screened	7555
Resistant lines identified (directly from germplasm)	66
Total single plant selections from germplasm screened	4940
Germplasm purified for resistance through single plant selections	433
Tolerant lines identified (mild mosaic/ringspot)	54
Resistant lines tested through multilocation tests	311
Lines resistant at more than one location	35
Breeding materials screened	4905
Atylosia spp. screened	10
Resistant *Atylosia* species	1 (*A. volubilis*)

The 66 germplasm lines that have been identified as resistant are listed below. Resistant lines (433) obtained through single-plant selections have not been listed for lack of space; however information will be furnished on request.

ICP-2630	7035	7428	7904	8077	8825
3782	7119	7480	7906	8113	8850
3783	7188	7867	7994	8120	8852
4344	7201	7869	7997	8136	8853
4725	7250	7871	8004	8145	8856
6630	7282	7873	8006	8466	8857
6986	7349	7878	8051	8501	8861
6997	7403	7898			
JM-2381	2389	2412	2448	2481	2486
2384	2392	2418	2456	2483	2496
2388	2396				

PI-394530	394571	395878	397731
394559	395043	396211	

We have thus been able to identify many sources of resistance and tolerance tothe sterility mosaic. Unfortunately, several of these have proved to be susceptible at Dholi in Bihar. This could be due to a different strain of the mite vector or the causal agent. Over 250 lines found resistant at ICRISAT were tested at Dholi in the 1979-80 season, in cooperation with the scientists of the Rajendra Agricultural University; only 16 lines were also resistant there. These 16 lines are being tested at several locations in India during the current season. ICAR and ICRISAT scientists are working jointly to strengthen multilocation testing, which is urgently needed to identify resistance sources.

Phytophthora Blight (*Phytophthora drechsleri* F. sp. *cajani*)

A "stem rot of pigeonpea" was described for the first timefrom India by Mahendra Pal et al. in 1970, although its suspected occurrence was reported by Williams et al. (1968). These workers observed the disease in serious form in the 1968-69 season at certain locations in northern India. The causal fungus was identified as *Phytophthora drechsleri* Tucker var. *cajani* Pal, Grewal, and Sarbhoy. Five years later, a "Phytophthora stem blight" of pigeonpea was described from the same areas of northern India (Williams et al. 1975). The species was not identified at that time, but was later described by the same group of workers as *Phytophthora cajani* Amin, Baldev, and Williams (Amin et al. 1978). Kaiser and Melendez (1978) described a "stem canker" caused by *Phytophthora parasitica* Dast. Recently, Kannaiyan et al. (1980), based on a detailed study, called the disease occurring in India Phytophthora blight, and the fungus, *Phytophthora drechsleri* f. sp. *cajani.*

This disease, already reported from northern India in Delhi and Uttar Pradesh, was observed in severe form at ICRISAT in 1976. Although we have not conducted extensive surveys for it, we suspect the disease occurs in most pigeonpea-growing areas, particularly during long wet spells, which are common during the first 3 months of crop growth. Information on losses caused by this disease is not available, butthere is no doubt that the disease has the potential to cause devastation in a susceptible cultivar.

The symptoms are characterized by the appearance of dark brown to purple lesions on stems, petioles, and leaves; many plants are killed.

Screening Procedures Adopted

We have developed and standardized a field technique and two pot techniques (Nene et al. 1980 b). The field technique involves rubbing inoculum at the base of the stem of each plant, followed by flood irrigation of the field. Another inoculation is carried out on surviving plants 30 days after the first inoculation. In one pot screening technique 5- to 10-day-old seedlings are inoculated by pouring aqueous suspension of the fungus culture around the base of seedlings, which are then watered freely. In the other technique, seedlings grown in pots are spray-inoculated with the fungus suspension. We have found a strong correlation between data from the pot- and field-screening techniques.

Sources of Resistance

Mahendra Pal et al. (1970) were the first to carry out screening for resistance; lines AS-3, 2357, and 4419 were found moderately resistant. At ICRISAT Center we initiated screening work in 1976-77 season. We have so far screened 3419 germplasm lines and identified 122 resistant lines. Also so far, 3069 breeding materials have been screened.

ICP lines that have been found resistant at ICRISAT Center and seed of which is available for testing, are:

28	1950	3945	7182	8104	8289
113	2153	4135	7185	8110	8328
231	2376	4141	7200	8117	8332
339	2505	4168	7232	8122	8466
580	2673	4699	7269	8124	8557
752	2682	4752	7273	8127	8558
913	2719	4765	7414	8131	8559
934	2736	4866	7533	8132	8560
1088	2974	4882	7624	8139	8562
1090	3008	5450	7657	8141	8564
1120	3259	5656	7701	8144	8568
1123	3367	5860	7754	8147	8579
1149	3741	6865	7795	8149	8603
1150	3753	6952	7798	8151	8610
1151	3840	6953	7810	8214	8619
1258	3861	6956	7837	8236	8675
1321	3867	6974	7910	8248	8692
1529	3868	7057	8087	8258	8700
1535	3891	7065	8101	8282	8701
1586	3899	7151	8103	8287	8868
1788	3937				

We did not have much difficulty in identifying resistance to Phytophthora blight; however, we discovered that many of our best lines were susceptible at Kanpur in Uttar Pradesh. We are convinced that a distinct race of the fungus exists at Kanpur. In collaboration with the staff of the C.S. Azad University of Agriculture and Technology we are presently testing near Kanpur 196 lines found promising at ICRISAT. We hope to identify lines with resistance to more than one race.

Multiple-Disease Resistance

There is an obvious need to identify lines having resistance to more than one disease and to more than one race of a pathogen. To obtain combined resistance, we have developed a 1.2-ha multiple-disease nursery in which the occurrence of wilt, sterility mosaic, and Phytophthora blight is ensured. We have identified several lines with resistance to more than one disease:

Wilt and sterility mosaic	ICP-3782, -4769, -5097, -6831, -7201, -7273, -7336, -7867, -8861, -8862, -8867, -8869; Purple-1 Sel., Cross no. 74342, and Cross no. 74363.
Wilt and Phytophthora blight	ICP-3753, -7182, -7273.
Sterility mosaic and Phytophthora blight	ICP-934, -4765, -4866, -5656, -6974, -7185, -7232, -7269, -7273, -7414, -8101, -8127, -8132, -8139, -8147, -8151.
Wilt, sterility mosaic, and Phytophthora blight	ICP-7273

As pointed out before, we have initiated multilocation trials to identify resistance to more than one strain of each of the three pathogens (in the case of sterility mosaic, possibly resistance to more than one strain of the vector).

Other Diseases

Witches' Broom

Witches' broom of pigeonpea was first described by Maramorosch et al. (1974). They discovered the presence of mycoplasma-like organisms as well as particles of a rhabdovirus in the diseased tissue. The disease is serious in the Dominican Republic and Puerto Rico, and has also been reported from Australia, Jamaica, NewGuinea, Taiwan, and Trinidad (Nene 1980). A similar disease has been observed in Bangladesh. No work on the identification of resistance sources has been initiated so far; considering the seriousness of the disease in the Caribbean, the need for systematic study of this disease cannot be overemphasized.

Rust (*Undo cajani*)

Rust on pigeonpea was first reported from India in 1906 (Sydow and Butler 1906). It has since been reported from Bermuda, Colombia, Kenya, Nigeria, Puerto Rico, Sierra Leone, Tanzania, Trinidad, and Venezuela (Nene 1980). In most countries the disease is not considered to be serious, but it has been observed to be severe on some new cultivars developed in Trin idad (e.g., UW-17). Thedisease does have the potential to cause severe damage. Tothe best of our knowledge, sources of resistance have not been identified.

Leaf Spot (*Carcoapora cajani*)

Pigeonpea leaf spot caused by C *cajani* has been reported from the Dominican Republic, India, Kenya, Malawi, Mauritius, Nigeria, Tanzania, Uganda, Venezuela, Zambia, and Zimbabwe (Nene 1980). Occasionally it has been reported to be serious. Onim and Rubaihayo (1976) identified UC-796/1, UC-2515/2, UC-2113/1, and UC-2658/1 to be resistant as well as high yielding.

References

ALAM, M. 1931. Administration report of the botanical section for the year ending 31 March 1931. Department of Agriculture, Bihar, Orissa, for the period from 1 April 1930 to 31 March 1931: 42-65.

ALAM, M. 1933. Rahar sterility. Proceedings, 20th Annual Meeting Indian Science Congress, Poona, sect. Agric. 43: 15-16.

AMIN, K. S., BALDEV, B., and WILLIAMS, F. J. 1978. *Phytophthora cajani,* a new species causing stem blight on *Cajanus cajan.* Mycologia 70: 171-176.

ANONYMOUS. 1950. Annual administration report of the Department of Agriculture, Uttar Pradesh, for the year ending June 30, 1949. 125 pp.

ANONYMOUS. 1953. Scientific report of the Indian Agricultural Research Institute for the year ending 30 June 1951. 120 pp.

ANONYMOUS. 1976. Testing of Arhar (pigeonpea) strains against wilt disease. Pesticides 10(2): 17.

BALDEV, B., and AMIN, K. S. 1974. Studies on the existence of races in *Fusarium udum* causing wilt of *Cajanus cajan.* SABRAO Journal 6: 201-205.

BOOTH, C. 1971. The genus *Fusarium.* Kew (Surrey), England: Commonwealth Mycological Institute.

BUTLER, E.J. 1906. The wilt disease of pigeonpea and pepper. Agriculture Journal, India 1: 25-36.

BUTLER, E. J. 1908. Selection of pigeonpea for wilt disease. Agriculture Journal, India 3: 182-183.

BUTLER, E.J. 1910. The wilt disease of pigeonpea and the parasitism of *Neocosmospora vasinfecta* Smith. Memoir, Department of Agriculture, India, Bot. Ser. 2: 1-64.

CAPOOR, S. P. 1952. Observations on the sterility disease of pigeonpea. Indian Journal of Agricultural Sciences 22: 271-274.

DASTUR, J. F. 1946. Report of the Imperial Mycologist. Pages 66-72 *in* Scientific Report, Agricultural Research Institute, New Delhi, 1944-45.

DEIGHTON, F. C. 1929. Report of the Mycological Section. Pages 14-19 *in* Annual Report, Lands and Forests Department, Sierre Leone, for the year 1928.

DESHPANDE, R. B., JESWANI, L. M., and JOSHI, A. B. 1963. Breeding wilt resistant varieties of pigeonpea. Indian Journal of Genetics 23: 58-63.

DEY, P. K. 1948. Plant pathology. Pages 39-42 *in* Administrative report of the Agriculture Department, U. P., 1946-47.

KAISER, W. J., and MELENDEZ, P. L. 1978. A *Phytophthora* stem canker disease of pigeonpea in Puerto Rico. Plant Disease Reporter 62: 240-242.

KANNAIYAN, J., RIBEIRO, O. K., ERWIN, D. C, and NENE, Y. L. 1980. *Phytophthora* blight of pigeonpea in India. Mycologia 72: 169-181.

MAHENDRA PAL, GREWAL, J. S., and SARBHOY, A. K. 1970. A new stem rot of arhar caused by Phytophthora. Indian Phytopathology 23: 583-587.

MARAMOROSCH, K., HIRUMI, H., KIMURA, M., BIRD, J., and VAKILI, N. G. 1974. Pigeonpea Witches' broom disease. Phytopathology 64: 582-583.

MCRAE, W. and SHAW, F. J. F. 1933. Influence of manures on the wilt disease of *Cajanus indicus* Spreng. and isolation of types resistant to the disease. Part II. The isolation of resistant types. Pages 37-68 *in* Imperial Council of Agricultural Research Scientific Monograph 7, Pusa, India.

MITRA, M. 1931. Report of the Imperial Mycologist. Pages 58-71 *in* Scientific Report, Agricultural Research Institute, Pusa, 1929-30.

MUNDKUR, B. B. 1946. Report of the Imperial Mycologist. Pages 57-63 *in* Scientific Report, Agricultural Research Institute, New Delhi, for the triennium ending 30 June 1944.

NARAYANASWAMY, P., and RAMAKRISHNAN, K. 1965. Studies on the sterility mosaic disease of pigeonpea. I. Transmission of the disease. Proceedings, Indian Academy of Science (Section B) 62: 73-86.

NENE, Y. L. 1972. Viral diseases of pulse crops in Uttar Pradesh. G. B. Pant University of Agriculture and Technology Research Bulletin 4: 191.

NENE, Y. L. 1980. A world list of pigeonpea *(Cajanus cajan* [L.] Millsp.) and chickpea (*Cicer arietinum* L.) pathogens. ICRISAT Pulse Pathology progress report 8, Patancheru, A. P., India.

NENE, Y. L., and REDDY, M. V. 1976a. A new technique to screen pigeonpea for resistance to sterility mosaic. Tropical Grain Legume Bulletin 5:23.

NENE, Y. L., and REDDY, M. V. 1976b. Screening for resistance to sterility mosaic of pigeonpea. Plant Disease Reporter 60: 1034-1036.

NENE, Y. L, KANNAIYAN, J., HAWARE, M. P., and REDDY, M. V. 198.0a. Review of the work done at ICRISAT on soil-borne diseases of pigeonpea and chickpea. Pages 3-39 *in* Proceedings, Consultants' Group Discussion on Resistance to Soilborne Diseases of Legumes, ICRISAT, 8-11 Jan 1979, Hyderabad, India. Available from ICRISAT, Patancheru, A. P. 502 324, India.

NENE, Y. L., KANNAIYAN, J., and REDDY, M. V. 1980b. Techniques to screen for resistance to some pigeonpea diseases. ICRISAT Information Bulletin (In press).

NEWTON, W., and PEIRIS, J. W. L. 1953. Virus diseases of plants in Ceylon. FAO Plant Protection Bulletin 2(2): 17-21.

ONIM, J. F. M., and RUBAIHAYO, P. R. 1976. Screening pigeonpea for resistance to *Mycovellosiella cajani'.* SABRAO Journal 8: 121-125.

RAMAKRISHNAN, K., and KANDASWAMY, T. K. 1972. Investigations on virus diseases of pulse crops in Tamil Nadu. Tamil Nadu Agricultural University, Final Technical Report, Coimbatore, India.

RAUT, N. K., and BHOMBE, B. B. 1971. A review of the work of selections of tur varieties resistant to *Fusarium* wilt at College of Agriculture, Parbhani (Maharashtra). College of Agriculture Magazine, Parbhani 12: 37-42.

SETH, M. L. 1962. Transmission of pigeonpea sterility by an eriophyid mite. Indian Phytopathology 15: 225-227.

SINGH, D. V., and MISHRA, A. N. 1976. Search for wilt-resistant varieties of red gram in Uttar Pradesh. Indian Journal of Mycology and Plant Pathology 6: 89.

Su, U. 1931. Plant Diseases in Burma. International Bulletin of Plant Protection 5: 141-142.

SYDOW, H., and BUTLER, E. J. 1906. Fungi Indiae Orientalis. Part 1 Ann. Mycol. 4: 424-445. (Quoted from Butler and Bisby, 1960. The fungi of India. Indian Council of Agricultural Research: New Delhi. 552 *pp.).*

VAHEEOUDDIN, S. 1956. Selection *of tur* (*Cajanus cajan* L.) resistant varieties against wilt *(Fusarium udum* Butler). Agricultural College Journal of Osmania University 3: 12-13.

VAHEEOUDDIN, S. 1958. Evolving wilt resistant strains of red gram. Andhra Agricultural Journal 5: 163-164.

WILLIAMS, F. J., AMIN, K. S., and BALDEV, B. 1975. *Phytophthora* stem blight of *Cajanus cajan.* Phytopathology 65: 1029-1030.

WILLIAMS, F. J., GREWAL, J. S., and AMIN, K. S. 1968. Serious and new diseases of pulse crops in India in 1966. Plant Disease Reporter 52: 300-304.

Diseases of Pigeonpea in the Caribbean Area

C. W. D. Brathwaite*

Abstract

Pigeonpea, with a seed protein content of up to 24%, contributes significantly to the nutrition of the Caribbean people. However, crop yields are low on the average. Diseases are among the major yield reducers. Twenty-one have been reported from the area, and this paper surveys available literature on the most serious ones.

Pigeonpea, *Cajanus cajan* (L) Millsp., apparently reached the Caribbean from Africa during the days of the slave trade. It is now grown widely in the Caribbean, either as a backyard crop or on farms of 4 ha or less. In small Island states, the crop is grown either as a border around plots of other crops, such as sugarcane, or in a system of intercropping with maize and root crops. Pigeonpea is held to be rich in high-quality protein and is eaten with rice throughout the region. The dried seed has a protein content of about 24%, and the widespread consumption of the seeds makes a significant contribution to the nutritional requirements of the Caribbean people.

According to a recent survey (Anonymous 1978), pigeonpea is produced on 27 235 ha, giving a total production of 23 819 tonnes (metric ton) and an average yield of 691 kg/ha. The crop accounts for about 6% of the food legumes produced in the region. Production of the crop varies considerably, ranging from 1 tonne in Barbados to 14 545 tonnes in the Dominican Republic, which is responsible for about 60% of the total regional production of pigeonpea (Table 1).

Diseases of Pigeonpea

Yields of pigeonpea in the Caribbean, estimated at about 691 kg dried seed/ha, are low when compared with yields obtainable in other parts of the world. While an array of cultural, agronomic, and technological factors may be important in this low productivity, pests and diseases are also important contributing factors. According to Mohammed (1978) there are about 21 diseases of pigeonpea reported from the Caribbean region (Table 2).

Table 1. Area and production of pigeonpea in the Caribbean.

Country	Area under cultivation (ha)	Total production (tonnes)	Average yield (kg/ha)
Dominican Republic	13 941	14 545	1360
Haiti	6 667	4 000	600
Jamaica	2 800	1 510	840
Panama	2 703	3 436	578
Grenada	607	36	674
Guadeloupe	200	60	300[a]
Trinidad and Tobago	178	150	750
St. Vincent	56	50	1000
St. Lucia	52	16	300*
Guyana	16	7	437
Antigua	8	5	673
St. Kitts/Nevis/ Anguilla	4	3	673
Barbados	3	1	800
Total	27 235	23 819	691

Source: Anonymous 1978.
a. Estimated yield.

* Department of Plant Pathology, University of the West Indies, St. Augustine, Trinidad.

Table 2. Diseases of pigeonpea in the Caribbean.

Country	Characteristics of disease	Causal agent	Authority
Puerto Rico	Canker	*Botryosphaeria xanthocephala*	Tucker 1927
		Phoma sp.	Alvarez 1960; Lopez Rosa 1969
	Wilting and rotting	*Pellicularia filamentosa*	Theis et al. 1967
		Rhizoctonia sp.	Jehle and Wood 1926
	Leaf spots	*Cercospora cajani*	Jehle and Wood 1926
		Colletotrichum cajani	Tucker 1927
		Phyllosticta cajani	Jehle and Wood 1926
		Vellosiella	Jehle and Wood 1926
	Rust	*Uromyces* sp.	Jehle and Wood 1926
	Covvpea mosaic	Virus	Adsuar 1964
	Proliferation ("Witches' broom")	MLO and rhabdo-type virus	Maramorosch et al. 1974
	Rhynchosia (yellow) mosaic	Viroid	Bird 1962; Maramorosch et al. 1974
Dominican Republic	Leaf spots	*Cercospora cajani*	Ciferri 1927
	Proliferation ("Witches' Bloom")	MLO and rhabdo-type virus	Maramorosch et al. 1974
Bermuda	Rust	*Uromyces dolicholi* Arth. (*Uredo cajani* Syd.)	Waterston 1944
	Wilting and rotting	*Sclerotinia sclerotinum*	Waterston 1944
Jamaica	Canker (stem)	*Macrophomina phaseoli* (Maubl.) Ashby	Leather 1967
	Leaf spots (brown)	*Mycovellosiella cajani* P. Hann Rangel ex Trotter	Leather 1967
	"Frog's eye"	*Phyllosticta cajani* Syd.	Leather 1967
	Rust	*Uredo cajani*	Naylor 1974
	Hopper burn (mild "Witches' broom")		Naylor 1974
	Mosaic (yellow)	Virus or viruses found in weed *Phaseolus lathyroides*	Naylor 1974
	Yellowing and die-back syndrome after first crop	Leaf analysis showed possible manganese deficiency, although foliar sprays plus manganese showed no reversal of symptoms	Hammerton 1973
Trinidad	Canker (collar and stem)	*Physalospora* sp. Imperfect stage = *Phoma* or *Macrophoma*	Leach and Wright 1930
	Canker (stem)	*Macrophomina phaseolina* (Tassi) Goid	Leather 1974
	Wilting and rotting	*Helicobasidium purpureum*	Baker and Dale 1951
		Macrophomina phaseoli (Maubl.)	
		Sclerotium rolfsii	Phelps 1974
	Rust	*Uromyces dolicholi* (= *Uredo cajani)*	Baker and Dale 1951
	Leaf spot (brown)	*Cercospora cajani IMycovellosiella cajani)*	Baker and Dale 1951
	Leaf spot ("Frog's eye")	*Phyllosticta cajani*	Leather (personal communication)
	Web blight	*Corticium solani*	Leather 1974
	"Blight" on flowers	*Chaenophora* sp.	Leather 1976; not confirmed

Source: Mohammed 1978.

Fungal Diseases

The major fungal diseases of pigeonpea in the Caribbean are rust disease, collar and stem canker, southern blight, and leaf spots (Pierre 1979).

Rust

This disease is characterized by the development of numerous rust-colored spots on the lower surface of the leaf. Infected leaves quickly turn yellow and fall. The disease is caused by *Uredo cajani* Syd. Some workers report the disease as being caused by *Uromyces dolicholi* Arthur. The latter fungus is found on *Rhynchosia,* a wild legume, whereas *Uredo cajani* is found on pigeonpea. The distinction between the two fungi is based on comparison of the telial stages and teliospores have not been found for *Uredo cajani* in the Caribbean.

The disease is widespread in the Caribbean, and severe attacks that result in defoliation would be expected to reduce yields significantly. Mohammed (1978) has shown that disease intensity increased with the onset of flowering. Dense plantings and theformation of a closed canopy seem to provide a microclimate favorable to rust development. *U. cajani* appears to be photosensitive, sporulating with diurnal periodicity. Light rain, wind, and overcast skies enhance spore release, dispersal, and rust development. McKie (1976) found that *U. cajani* will give 100% spore germination in either distilled water, tap water, or 0.5% glucose. This implies that uredospores will germinate as long as water is present. The germ tubes grew more slowly in tap water and formed appressoria at shorter lengths than in glucose or distilled water. Rampersad (1976) developed an in vivo technique of observing uredospore germination and found that uredospores penetrated the leaf within 8 hours after inoculation. Barnes (1973) reported that minute white spots were visible on leaves 7 days after inoculation, and the first uredosori opened on the 12th day. On the 14th day after inoculation, all visible uredosori were open.

Pierre (1971), Naylor (1974), Barnes (1973), and Leather (1976) have all reported satisfactory control of rust disease of pigeonpea with maneb (dithane M45). Barnes showed that after 2 weeks, the infection index for maneb-treated plants did not increase, while that for untreated plants increased. Moreover, maneb delayed leaf fall during the reproductive phase of plant growth. Barnes obtained both increase in the number of pods per plant and increase in mean dry weight per pod (Table 3).

Table 3. Effect of maneb on pod number and dry weight of pods per plant.

Treatment[a]	Pod number	Mean dry weight
Control	22.9	9.82
Maneb-treated	34.7	18.80

Source: Barnes 1973.
a. Differences between treatments significant at the 5% level.

Mohammed (1978) has shown that determining spore concentration daily, identifying sources of inoculum, and observing weather conditions can assist in the prediction of vast disease incidence.

Mohammed (1978) did not find any resistant lines. Many of the new early-maturing varieties were not resistant, but they escaped severe infection by maturing before the buildup of an epidemic. Mohammed is of the view that the occurrence of narrow leaflets in the Indian varieties may possibly increase light infiltration through the plant and minimize shading of lower leaves, thus limiting rust development. There is no current evidence for races of *U. cajani* in the Caribbean.

Stem and Collar Canker

This disease was reported in Trinidad by Leach and Wright (1930) who associated it with *Physalcspora* spp. The imperfect stage of the fungus was thought to be either *Phoma* or *Macrophoma.* More recently, Garcia (1960) reported an epidemic of Phoma canker in Puerto Rico. The disease was prevalent in the Penuelas *area* of Puerto Rico and was characterized by the presence of swollen, cankerous areas 2 to 3 cm long on the branches and stems. The lesions generally enlarged longitudinally, swelling and breaking open the bark and becoming more cankerous with age. Seedlings were attacked early, with sooty spots being the most characteristic symptom. The disease was reportedly caused by a species *of Phoma* that was characterized by theformation of papillate pycnidia of variable size.

The disease reported by Leach and Wright and that reported by Garcia appear to be identical in symptomatology. Leach and Wright, however, found the perfect stage, *Physalospora* sp., while Garcia only found a single imperfect stage, *Phoma* sp. In addition, the former authors did report the presence of a *Diplodia* sp., which they thought to be responsible for the carbonaceous appearance of the cankers, while Garcia observed that the carbonaceous appearance on cankers was present in plants inoculated with *Phoma* sp. alone. Kaiser and Melendez (1978) have recently *reported anew* canker disease of pigeonpea in Puerto Rico caused by *Phytophthora parasitica.* The disease is characterized by necrotic depressed lesions on the stem and branches, resulting in wilting. Isolates from eggplant, pigeonpea, and tomato were pathogenic to pigeonpea. Wounding favored infection with all isolates. *Macrophomina phaseolina* (Tassi) Goid has been reported as the causal agent of stem canker in Trinidad (Leather, unpublished).[1] *Macrophomina phaseolina* is synonymous with *Macrophoma cajani* Syd and Butt (1916), *Macrophoma phaseolina* Tassi (1901), and *Macrophoma phaseoli* Maubl. (1905). Stem cankers caused by *Macrophomina* sp. and *Diplodia cajani* have been reported from India, The symptoms described for the diseases caused by these pathogens are similar to those described for *Phoma* canker by Garcia. It seems likely that the symptoms ofthis disease are produced by more than one pathogen.

Leach and Wright (1930) and Leather (unpublished) have concluded that since the disease appears late, it is unlikely to be a major problem when a single crop is to be taken. However, Alvarez (1960) described an epidemic of this disease in pigeonpea in Puerto Rico in 1954. Consequently, the importance of the disease cannot be disregarded, especially in dense stands of pigeonpea in a row-crop system.

Southern Blight

Southern blight of pigeonpea caused by *Sclerotium rolfsii* was reported by Phelps et al. in Trinidad in 1974. The fungus was previously reported on pigeonpea (Anonymous 1960), but this was the first study of the disease in the Caribbean. The disease is characterized by the drooping of leaves, and eventually plants wilt. A white weft of mycelium forms atthe base of the stem; sometimes this spreads up onto the stem in a fan-like manner and sometimes it spreads onto the soil, especially in wet weather. Sclerotia are formed in the white mycelial masses on the stem. These are white at first but gradually become brown and are the most characteristic sign of the disease from a diagnostic point of view. Southern blight was found in Trinidad in dwarf varieties of pigeonpea that were planted after incorporation of bamboo grass, *Paspalum fasciculatum,* into the soil.

Phelps et al. (1974) demonstrated that the fungus actively colonizes pieces of dead bamboo grass, from which it is able to attack the host plant. Infection did not take place when the grass substrate was more than 2.0 cm from the living host. The fungus made little mycelial growth in field soil, but grew actively when bamboo grass clippings were added to the soil. Greenhouse studies confirmed the pathogenicity of the fungus and showed that pigeonpea plants are susceptibleup to 27 days after germination. Resistance is exhibited between 27 and 45 days; after this the plants appear to be immune. All determinate varieties proved susceptible to the pathogen, but some resistance was found among certain semideterminate varieties. Methods of screening for resistance and the mechanism of this resistance are currently being investigated.

Control of *S. rolfsii* is often difficult in the field; however, general sanitation and tillage methods that bury crop refuse and weeds are considered the best cultural methods of disease control.

Leather (unpublished) has shown that captan effectively prevents seed coat infection in vitro and, in combination with Gamma BHC, significantly increases the number of established seedlings 6 weeks after sowing.

Leaf Spots

Leaf spot caused by *Mycovellosiella cajani* (P. Henn) Rangel et Trotter (Syn. *Cercospora cajani* [Henn]) has been reported from many of the

1. ODA/UWI multidisciplinary pigeonpeaproject report, Department of Biological Sciences, University of the West Indies, St. Augustine, Trinidad.

Caribbean islands. Leather (unpublished) reported in 1976 that the disease on leaves infected by *Uredo cajani* and pointed out that the disease can easily be overlooked, as the lesions are not readily definable. No studies have been carried out on the importance of this disease in the Caribbean, but studies in Uganda (1975) have shown that this leaf spot can cause grain yield losses of up to 68% and that consequently thedisease should be kept under surveillance. A leaf spot caused by *Phyllosticta cajani,* which is sometimes associated with canker, has been reported from Trinidad by Leach and Wright (1930).

Other Fungal Diseases

Leather (unpublished) observed a flower blight in Trinidad in 1976 and attributed the disease to a species of *Choanephora.* Tucker (1927) had also reported a flower blight from Puerto Rico, but this was attributed to *Colletotrichum cajani.* The economic significance of these diseases has apparently not been evaluated; however, since physiological studies suggest that limitations to yield may lie in the flowering and pod-setting processes, a flower blight may be of economic importance.

Leather has also reported a web blight caused by *Corticium solani* in Trinidad.

Seed-borne Pathogens

Poor seed germination is a major factor affecting the production of pigeonpea. To determine whether pathogenic microorganisms present on or in seed were associated with this phenomenon, Ellis et al. (1973) carried out studies on the crop in Puerto Rico. They found that pigeonpea seed used for planting had an in vitro germination and incidence of internally seed-borne fungi, of 60% and 70% respectively. The following internally seed-borne fungi were isolated from pigeonpea seeds: *Phomopsis* sp., *Lasiodiplodia theobromae; Fusarium semitectum; Alternaria tenuissima; Aspergillus* sp.; *Penicillium* sp; *Macrophomina* sp; *and Rhizopus* sp. The percentage of seeds infected by fungi was not below 65% for all cultivars. *Phomopsis* sp. and *L. theobromae* were almost consistently isolated from dead (non-germinated) seeds. *F. semitectum* was frequently isolated from dead seeds and *A. tenuissima* was most frequently isolated from germinated seeds. The occurrence of total internally seed-borne fungi, *Phomopsis sp., L theobromae, F. semitectum,* and A *tenuissima,* was negatively correlated with emergence in the field. As seed infection by thesefungi increased, the percentage field emergence decreased. In addition, these fungi appeared to affect the physical appearance of the seed. Wrinkled and discolored seeds had a much higher percentage infection by fungi than seeds that had good physical appearance (uniformity in shape, color, and size), which appears to be an important characteristic of high-quaiity pigeonpea seed. In another study, Ellis et al. (1978) demonstrated that a large number of fungicides, includ ing thiram, carboxin, and Demosan effectively reduced the level of seed infection and resulted in increased seedling emergence.

Viral Diseases

Two diseases with virus-like symptoms are of importance in the Caribbean, Rhynchosia mosaic and "Witches' broom."

Rhynchosia Mosaic (Yellow Mosaic)

This disease is known to occur in Jamaica and Puerto Rico. It is characterized by the presence of bright yellow patches interspersed with green leaves. Studies by Maramorosch et al. (1974) have shown that the causal agent is transmitted by a white fly *Bernisia tabaci* and a reservoir of inoculum exists in the wild legume, *Rhynchosia minima.* Electron microscopy studies failed to reveal the presence of the causal agent. The workers are of the view that the disease may not be due to viruses but to viroids or a group of microorganisms not yet known to cause plant diseases.

"Witches' Broom," or Proliferation Disease

This disease has been reported on pigeonpea in Jamaica, Haiti, and the Dominican Republic (Maramorosch et al. 1974). The disease is characterized by prolific and clustered branching of the plant. Leaves appear pale green and are reduced in size. The flowers are produced in clusters, their petioles generally elongated; many fail to develop beyond the bud stage, and the plants fail to set fruit. Sometimes the disease affects only a part of the plant. In electron microscopy studies of diseased plants, mycoplasma-like organisms and rhabdovirus like particles were found in the phloem. It is not known whether the disease is due to the mycoplasma-like organisms, the rhabdoviruses, or to a combination of both. The economic significance of these diseases has not been determined.

Plant-Parasitic Nematodes

Bessey (1911), as cited by Ayala (1962), was the first to report the occurrence of root-knot nematode *Meloidogyne* spp. on pigeonpea. The nematodes were abundant but seemed to cause little damage *to* the plants. Since Bessey's work, several workers have reported the occurrence of nematodes on pigeonpea in various parts of the world. Ayala, carrying out detailed investigations on nematode infection of the crop, found that pigeonpea plants growing close to the laboratory at the Agricultural Experiment Station in Puerto Rico were heavily infected with root-knot nematodes. The infected roots had swellings grouped together to form club-shaped root tips. Most of the secondary roots were galled, and attack of primary *roots* resulted in the formation of corky tissue from which a large number of female nematodes could be excised. Pronounced proliferation of the roots, resulting in "brooming," and club-shaped roots were prevalent when root tips were attacked. No above-ground symptoms of nematode infection were observed. The nematode was identified as *Meloidogyne javanica* (Treub 1885), Chitwood (1949) and it was thought to be the first time the nematode was reported in the Western Hemisphere.

Subsequently, studies by Ayala and Ramirez (1964) showed that the reniform nematode *Rotylenchulus reniformis* was also associated with pigeonpea in Puerto Rico. Singh and Farrell (1972) also reported the occurrence of *R. reniformis* on pigeonpea in Trinidad. However, no studies on the effect of this nematode on growth and yield of pigeonpea appear to have been carried out.

Hammerton (1973) reported a chlorosis and dieback of pigeonpea plants grown at Lawrence field in Jamaica. The young leaves were chlorotic and old shoots were dying from the tips. This dieback progressed down the plant until the entire plant died. The symptoms were not characteristic of any reported disease of pigeonpea. Consequently, Hutton and Hammerton (1975) investigated the problem from two angles. First, tissue and soil analyses were carried out to determine whether the symptoms may be associated with a nutrient deficiency. Second, the presence of plant-parasitic nematodes in the field was investigated. The results of the nematode investigations revealed the presence of *Rotylenchulus reniformis, Tylenchorhynchus* sp., *Helicotylenchus* sp., *Pratylenchus* sp., *Scutellonema* sp., *Longidorus* and *Hoplolaimus* sp. The most abundant nematode in soil samples was *R. reniformis.* Plots were treated with nematicides and then planted with pigeonpea. Although nematicidal treatments resulted in increased yield of pigeonpea, the distribution of yellowed plants was erratic and unrelated to the treatment. Consequently, nematodes were not thought to be the cause of the problem.

Analysis of the leaf tissue revealed low levels of Mn; however, the yellowing was not reversible by foliar application of micronutrient solutions. Consequently, Hammerton concluded that a deficiency of Mn was not the primary cause of the disease but is associated with the symptom. Further investigation of the syndrome is warranted.

References

ADSUAR, J. 1964. A mosaic disease of cowpea *(Vigna sinensis* Savi) in Puerto Rico. Journal of the Agricultural University of Puerto Rico 48(3): 264.

ALVAREZ, G. L.A. 1960. Phoma canker of pigeonpea in Puerto Rico. Journal of the Agricultural University of Puerto Rico 44(1): 28-30.

ANONYMOUS. 1960. Index of plant diseases. USDA Agricultural Research Service Agriculture Handbook 165. Washington, DC, USA: USDA.

ANONYMOUS. 1978. Food legumes in the Caribbean, Central America and Panama — status and possibilities. A report submitted to the FAO Regional

Office for Latin America by the Caribbean Agricultural Research and Development Institute. 70 pp.

AYALA, A. 1962. Research notes: Occurrence of the nematode *Meloidogyne javanica* on pigeonpea roots in Puerto Rico. Journal of the Agricultural University of Puerto Rico 46: 154-156.

AYALA, A., and RAMIREZ, C. T. 1964. Host range, distribution and bibliography of the reniform nematode, *Rotylenchus reniformis* with special reference to Puerto Rico. Journal of the Agricultural University of Puerto Rico 48: 140-161.

BARNES, R. F. 1973. A preliminary list of literature on pigeonpea *Cajanus cajan* (L) Millsp. Dept. of Biological Sciences Plant Pathology Bulletin 1, University of the West Indies, St. Augustine, Trinidad.

BARNES, R. F. 1975. Report on experiments on pigeonpeas. The report of the Grain Legume Research Programme 1974/75, Department of Biological Sciences, University of the West Indies, St. Augustine, Trinidad, (unpublished).

BAKER, R. E. O., and DALE, W. J. 1951. Fungi of Trinidad and Tobago. Mycology paper 33. 113 pp.

BIRD, T. 1962. A white-fly transmitted mosaic of *Rhynchosia minima* and its relation to tobacco leaf curl and other virus diseases of plants in Puerto Rico. Phytopathology 52(3): 286. (Abstract.)

BRATHWAITE, C. W. D. 1979. The pathology of pigeonpea. Presented at the Regional Workshop on Tropical Grain Legumes. University of the West Indies, 18-22 June 1979, St. Augustine, Trinidad.

CIFERRI, R., and GONZALES, F. R. 1927. Hongos parasitos y profitos de la Republica Dominica (9th Series) Bol. R. Sve. Espanola Hist. Nat. 27: 68-81.

ELLIS, M. A., PASCHAL, E. H., RAVALO, E. J., and ROSARIO, EILEEN, 1978. Effect of growing location on internally seed-borne fungi, seed germination, and field emergence of pigeonpea in Puerto Rico. Journal of the Agricultural University of Puerto Rico 62: 355-360.

ELLIS, M. A., SMITH, R. S., and ZIMBRANO, O. 1978. Effect of fungicide seed treatment of field emergence of poor and good quality pigeonpea *(Cajanus cajan).* Journal of the Agricultural University of Puerto Rico 62: 8-12.

GARCIA, L. A. A. 1960. Phoma canker of pigeonpea in Puerto Rico, Journal of theAgricultural University of Puerto Rico 44: 28-30.

HAMMERTON, J. L. 1973. A yellowing and dieback syndrome of pigeonpea, *Cajanus cajan* (L). Millsp. Pages 197-208 *in* Proceedings, 11th Caribbean Food Crop Society Meeting, Barbados, West Indies.

HUTTON, D. G., and HAMMERTON, J. L. 1975. Investigating the role of *Rotylenchus reniformis* in a decline *of* pigeonpea. Nematropica 5(2): 24. (Abstract.)

JEHLE, R. A., and WOOD, J. I.1926. Diseases of field and vegetable crops in the United States in 1925. Plant Disease Reporter (Supplement) 45: 152.

KAISER, W. J., and MELENDEZ, P. L. 1978. A *Phytophthora* stem canker disease of pigeonpea in Puerto Rico. Plant Disease Reporter 62: 240-242.

LEACH, R., and WRIGHT, J. 1930. Collar and stem canker of pigeonpea *(Cajanus cajan)* caused by a species of *Physalospora.* Memoir, Imperial College of Agriculture Mycology Series 1, Trinidad. 12 pp.

LEATHER, R. I. 1967. A catalogue of some plant diseases and fungi in Jamaica, Ministry of Agriculture Bulletin 61, New Series, Kingston, Jamaica.

LOPEZ ROSA, J. M. 1969. *Phoma* sp.: the causal agent of pigeonpea canker. Phytopathology 59(10): 1348. (Abstract.)

MARAMOROSCH, K., HIRUMI, and KIMURA, M. 1974. Diseases of pigeonpea in the Caribbean area: an electron microscopy study. FAO Plant Protection Bulletin 22: 32-36.

MCKIE, M. O. P. 1976. A study of the germination of uredospores of *Uredo cajani* in tap water, distilled water and 0.5% glucose. Year III, B.Sc. Agriculture Project, Faculty of Agriculture, University of the West indies, St. Augustine, Trinidad.

MOHAMMED, CAROLINE L. 1978. Preliminary investigation in pigeonpea rust, *Uredo cajani* Syd. M.Sc. Thesis, Faculty of Agriculture, University of the West Indies, St. Augustine, Trinidad. 190 pp.

NAYLOR, A. G. 1974. Diseases of plants in Jamaica. Agricultural Information Services, Ministry of Agriculture, Kingston, Jamaica. 129 pp.

ONIM, J. F. M. 1974. Improvement of pigeonpea — Development of resistance to *Mycovellosiella cajani.* M.Sc. Thesis, Makerere University, Uganda.

PIERRE, 1979. Diseases of food legumes in the Caribbean. Presented at the Workshop on Tropical Grain Legumes. University of the West Indies, 18-22 June 1979, St. Augustine, Trinidad.

PHELPS, R. H., OUDIT, I. L., and PAGE, C. 1974. Southem blight (*Sclerotium roffsii),* a new disease on pigeonpea (*Cajanus cajan*) *in* Proceedings, Symposium on the Protection of Horticultural Crops in theCaribbean. Department of Crop Science, University of the West Indies, St. Augustine, Trinidad.

RAMPERSAD, M. 1976. Determination of uredospore germination in pigeonpea. Applied Botany Study Project. Department of Biological Sciences, University of the West Indies, St. Augustine, Trinidad.

WATERSTON, J. M. 1944. Plant Pathology. Report of the Department of Agriculture, Bermuda, 1943: 7-8.

Some Aspects of Weed Management in Pigeonpeas

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Abstract

The present status of weed research on pigeonpea is reviewed, and priorities for future research are listed. Pigeonpea is a poor weed competitor during its initial slow growth; therefore, weed control is critical during the first 5 to 7 weeks of crop growth. Weed infestation depends mainly upon the extent of primary tillage and seedbed tilth. Early in the season, the weed flora usually comprise annual grasses, followed later by perennial sedges and broad-leaved weeds. Effectivepreemergence herbicides includeprometryn, ametryn, alachlor, nitrofen, dinitramine, chlorbromuron, chlorpropham, EPTC, and trifluralin. Paraquat, diquat, and MSMA are being widely used as postemergence herbicides. The results of weed research in pigeonpea-based intercropping systems, with particular emphasis on studies conducted at ICRISAT Center, are summarized. It is concluded that ecophysiological studies should be intensified to improve weed control by agronomic practices and to characterize and quantify weed competition in relation to crop age and cropping systems.

Pigeonpea (*Cajanus cajan* [L.] Millsp.), because of its slow initial growth rate, is very sensitive to weed competition in the first 45 to 60 days of growth. Only when the plants have reached a height of about 1 m can they effectively compete with the weeds. Therefore, effective weed control at the early growth stages of the crop is one of the most important factors contributing to high yields. In many rainfed pigeonpea-growing areas, optimum land preparation is seldom done, and weeds cause severe yield losses, even up to 90% and above (Saxena and Yadav 1975; Shetty 1977).

Some of the common weeds associated with pigeonpea are *Cyperus rotundus, Echinochloa* sp, *Digitaria* sp, *Dactyloctenium aegyptium, Setaria glauca, Amaranthus* sp, *Celosia argentea, Commelina benghalensis, Phyllanthusniruri, Digera arvensis,* and *Euphorbia* sp. If pigeonpea is grown as a rainfed crop, the early-season flora mainly comprises annual grasses followed later by perennial sedges and broad-leaved weeds (Shetty and Krantz 1980).

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In the trials conducted at ICRISAT Center (ICRISAT 1977) weed infestation was about the same in the early part of the growing season on both Alfisols and Vertisols; however, late-season dry weights of weeds were two to four times higher on the Vertisols than on the Alfisols. The initial weed infestation depends mainly upon the extent of primary tillage and the tilth of the seedbed. Besides competing for resources such as moisture, nutrients, and light, some major weeds — *Cyperus rotundus* and *Digera alternifolia,* for instance — are known to have an allelopathic effect on pigeonpea (Misra et al. 1968; Dubey 1973).

At present, weeds are controlled manually, mechanically, or chemically. In India, where 90% of the world's pigeonpea is grown, manual and/or mechanical methods are morecommon. Weed control methods vary greatly with the status of agriculture in the producing countries and the nature of the cropping systems. Weed control practices in pigeonpea should therefore be assessed not only in sole crops but also in mixed or intercrops where pigeonpea is one of the components.

Present Status of Research on Weeds in Pigeonpea

Weed research on pigeonpea has been confined mainly to chemical weed control under the sole-crop system (Table 1). Studies on crop-weed competition and cultural and biological methods of weed control are minimal; investigations related to cropping systems involving pigeonpea are very limited.

Chemical Control

Kasasian and Seeyave (1969) reviewed weed control in *C. cajan* in the West Indies. In Trinidad, Kasasian (1964) found that applications of 1.1 to 2.2 kg/ha of ametryn, prometryn, or prometone, 1.1 to 4.5 kg/ha of chloramben, and 2.2 to 9.0 kg/ha of diphenamid were most promising. It was indicated that an effective weed control program was prometryn (preemergence at 1.1 kg/ha), followed by paraquat at 0.55 kg/ha as a directed spray for subsequent (plant height 0.45 m) control. In Guyana, diquat proved effective (Poonai 1962); at 0.3 kg in 112 l of water/ha diquat applied between rows in 2-month-old crops desiccated all the weeds present without adversely affecting the crop. At a higher concentration (0.9 kg/ha), the chemical killed all weeds within 3 days and slightly affected the crop; however, crop recovery occurred and the treated plots observed 1 month after application grew better than the control.

Kasasian (1971) also observed that dwarf strains of pigeonpea were more susceptible to weeds than the taller types. In Trinidad, the critical period of crop-weed competition was the first 5 to 7 weeks in tall pigeonpeas. The herbicides found effective were: EPTC and Vernolate (1-2 kg/ha) as incorporated preplanting applications, prometryn (1 kg/ha), chloramben (2 to 4 kg/ha) as preemergence applications and paraquat (1-2 kg/ha) as postemergence directed sprayings. Hammerton (1972) observed that preemergence application of chloroxuron (1.7 kg/ha) or chlorbromuron (2.2 kg/ha) gave good weed control up to 7 to 9 weeks. He concluded that these preemergence treatments followed by a single shielded paraquat spray of 0.28 kg/ha applied at 6 weeks after planting was satisfactory to prevent weed competition. He also observed that MSMA gave a better control of *Cyperus* than paraquat.

In the Dominican Republic, Jurgens (1972) observed that prometryn at 1.25 kg/ha preemergence proved superior to diphenamid, chlorthal and fluorodifen. However, treatment with alachlor + linuron proved economical. In Malaysia also, the mixture of alachlor and linuron, at 0.5 kg/ha each, gave excellent weed control though the chemicals proved phytotoxic when applied singly at a rate of 1 kg/ha (Anonymous 1977).

Abrams and Julia (1974) compared hand weeding and mechanical cultivation with the use of chemicals for weed control in Puerto Rico. Prometryn (3 kg/ha) applied preemergence, followed by paraquat (1 kg/ha) as directed postemergence application (pigeonpea plants 4.5 cm tall) gave the highest yield increase. The authors also observed that the crop requires at least 5 weeks to establish fully and cover the interrow space; therefore weed control is critical during this early period.

Other preemergence herbicides found effective in pigeonpea are chlorthal dimethyl at 6.75 kg/ha in Australia (Wallis et al. 1975) and trifluralin, pebulate, siduron, CDAA, chlorpropham, and dinoseb in the USA (Getner and Danielson 1965).

In India, several workers reported that alachlor and nitrofen applied preemergence (at 1 kg/ha) provide efficient weed control (Saxena and Yadav 1975; Sankaran and Damodaran 1974; Shetty 1977; Singh and Faroda 1977). Intercultivations carried out at 20 and 45 days after planting also performed effectively (Saxena and Yadav 1975; Singh and Faroda 1977). At ICRISAT, a number of herbicides were screened for their efficacy in pigeonpea. In the multicrop herbicide screening trials, prometryn, ametryn, alachlor, dinitramine, nitrofen, trifluralin and tribunil as preemergence applications proved promising (Shetty 1977).

Weed Control in Cropping Systems

In India, pigeonpea is mainly grown in association with other crops as an intercrop, and sole cropping of pigeonpea is rare. Formerly, therefore, very little attention was given to weed control on this "minor" crop grown mainly by "traditional" farmers. Recently, however, since scientists have begun to recognize the importance of intercropping in rainfed farming in the semi-arid tropics, weed control is being oriented more towards intercrop systems where pigeonpea is a major component.

Rao and Shetty (1976) advocated that for evolving integrated weed-management systems, many factors such as crop variety, crop density, crop geometry, and relative propor-

Table 1. Herbicide* effective on pigeonpea.

Herbicide effective in	Rate (kg/ha)	Time of application	Reference
England			
2-6 DBN (2.6 Dichloro-benzonitrile)	0.5 - 0.8	Preem	Barnsley and Rosher (1961)
Guyana			
Diquat	0.27	Postern	Poonai (1962)
Trinidad			
Prometryn + Paraquat	0.5 + 0.5	Postern	Kasasian (1964)
Trifluralin	0.6 1.7	Postern	
Prometryn	2	Preem	
USA			
Trifluralin			
Pebulate	Not known	Preem	Getner and Danielson (1965)
Siduron			
CDAA			
West Indies			
EPTC	1 - 2	Preplant	Kasasian (1969)
Prometryn + diphenamid	1 + 0.5	Preem	
Chlorbromuron	1.0	Preem	
Chloroxurun	1.7	Preem	
Paraquat	0.8	Postern	
EPTC + Vernolate	1 + 2	Preplant	Kasasian (1971)
Prometryn	1	Preem	
Chloramben	2 - 4	Preem	
Paraquat	1	Postern	
Chlorbromuron	2.2	Preem	Hammerton (1972)
MSMA + Prometryn	3.3	Postern	
Prometryn	1.1	Preem	
Dominican Republic			
Prometryn	1.25	Preem	Jurgens (1972)
Terbutryn	4.0	Not known	
Alachlor + linuron	1 +0.5	Preem	
Puerto Rico			
Prometryn	3.3	Preem	Abrams and Julia (1974)
Paraquat	1.8	Postern	
Malaysia			
Alachlor + linuron	0.5 + 0.5	Preem	Anonymous (1977)

Continued

Table 1. *Continued.*

Herbicide effective in	Rate (kg/ha)	Time of application	Reference
India			
Prometryn	0.5 - 2.0	Preem	Shetty (1977)
Ametryn	0.5 - 2.0		
Alachlor	0.5 - 2.0		
Dinitramine	0.5		
Nitrofen	0.5 - 2.0		
Trifluralin	1.0		
Alachlor + nitrofen	1.0+ 1.0	Preem	Singh and Faroda (1977)
Nitrofen	1.0	Preem	Saxena and Yadav (1975)

Preem = Preemergence; Postern = Postemergence.

Table 2. Relative weed-suppressing ability* of various crops in pure stands.

Crop	WSA days after planting 44	68
Setaria	73	73
Pearl millet	82	88
Maize	76	92
Sorghum	69	81
Castor	57	51
Pigeonpea	23	54
Cowpea	78	88
Groundnut	74	62

Source: Rao and Shetty 1976.

a. Weed-suppressing ability (WSA) =

$$\frac{\text{Dry wt of weeds from fallow} - \text{Dry wt of weeds from cropped plot}}{\text{Dry wt of weeds from fallow}} \times 100$$

Table 3. Effects of intercropping pigeonpea (HY-2) with cereals and legumes on growth of weeds 6 weeks after planting at ICRISAT, 1975.

Crop combination	Weed dry weights (g/m^2)
Pigeonpea/Sorghum (CSH-5)	92
Pigeonpea/Pearl millet (HB-3)	97
Pigeonpea/Cowpea (C-152)	60
Pigeonpea/Field bean	87
Pigeonpea sole crop	196

Source: Shetty and Rao 1977.

tions of the crops in the mixture should be taken into consideration. A series of weed research experiments was conducted at ICRISAT to quantify the effect of these different factors on crop-weed balance.

Intercrops for Weed Suppression

Shetty and Rao (1977, 1979) summarized the results of various field trials on different pigeonpea-based intercropping systems at ICRISAT. They found that where intercropping is not practiced with pigeonpea, the resources are wasted, and the vacant interrow space creates more weed problems. Earlier results (Tables 2, 3, and 4) indicated that 50 to 75% reduction in weed infestation was achieved through intercropping pigeonpea with crops like sorghum, millet, cowpea, mung bean, and groundnut. In all the intercropping systems the competitive character of the system was derived mostly from the various intercrops and very little was contributed by pigeonpea. This crop, which requires 80 to 90 days to develop a reasonable spread, benefits from intercropping with short-duration and fast-growing crops that tend to shiftthe balanceof crop-weed competition to the advantage of the crop during the critical early period of growth.

Intercropping pigeonpea with maize or cowpea suppressed weed growth most, fol-

Table 4. Dry weight of weeds (g/m^2) 44 days after planting in different pigeonpea- and sorghum-based intercropping systems and sole crops in Alfisols at ICRISAT, 1976.

Crop	Intercropped with Pigeonpea	Intercropped with Sorghum	Sole crop	Mean
Setaria (H-1)	45.9	49.7	45.6	47.1
Pearl millet (HB-3)	34.8	18.7	30.3	27.9
Maize (SB-23)	34.4	21.4	42.1	32.7
Castor (157-B)	70.9	41.7	73.9	62.2
Groundnut TMV-2	62.2	41.4	44.8	49.5
Cowpea (1152)	69.3	34.1	37.7	47.1
Mean	52.9	34.4	45.7	
No Intercrop (check)	132.2	53.3	174.1[a]	120.2
Mean	64.4	37.2	64.2	

Source: Rao and Snotty 1976.

a. Fallow

LSD (0.05) for comparison of means within groups 43.5.
LSD (0.05) for comparison of means of different groups 44.5.
LSD (0.05) for comparison of cropping systems 25.7.
LSD (0.05) for comparison of various intercrops 25.1.

lowed by mung, sorghum, and groundnut. Though associated with pigeonpea for a longer time (90 days) than the other crops, groundnut could not prevent weed growth in later periods, due mainly to slow initial growth coupled with low canopy, which favored early establishment of weeds. Systems with maize and sorghum as intercrops, on the other hand, recorded less weed growth not only up to intercrop harvest but also until the final harvest of pigeonpea.

"Smother" Crops for Weed Suppression

Field experiments to monitor increasing weed suppression with "smother" crops (Shetty and Rao 1979) indicate that the inclusion of additional crops — such as cowpea and mung — showed promise in reducing weeds and virtually replaced one hand-weeding without significantly affecting the yields of the main crop. There were no significant differences between sole pigeonpea yields and yields in smother cropping systems (pigeonpea + cowpea or mung). The advantage of smother cropping is the elimination of one hand-weeding plus some additional yield of the smother crop itself. However, there did not seem to be any additional gain in replacing both the hand-weedings and including additional smother crops in the sorghum/pigeonpea intercrop system (Figure 1).

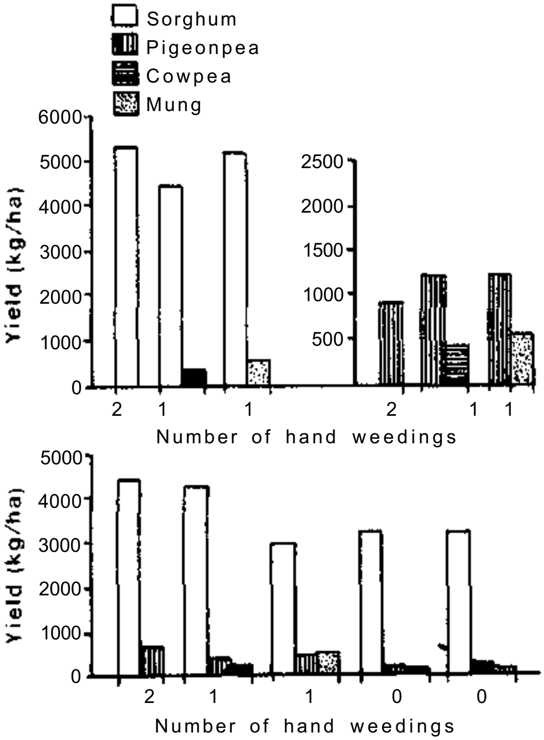

Figure 1. Influence of "smother" crops and number of hand weedings on crop yields at ICRISAT Center, 1977. (Source: Shetty and Rao 1979).

The inclusion of additional crops such as cowpea and mung resulted in less weed growth after one hand-weeding. After the harvest of smother crops, a new flush of weeds was observed. However, these late-season weeds were not as competitive with the pigeonpea crop as early-season weeds. These studies indicate that pigeonpea, which requires 80 to 90 days to develop a reasonable spread, benefits from intercropping with short-statured and quick-growing crops. The wide row spacing (1 to 1.5 m) required for sole-cropped pigeonpea cultivars provides ideal conditions for weeds to grow and multiply (Shetty and Rao 1977). Thus, intercropping can be a method of weed management if suitable component crops are grown with proper agronomic manipulation.

Increased Crop Density for Weed Suppression

The combined population pressure of the intercrop components enhances the ability of the crop to compete with weeds. Early results at ICRISAT (Figure 2) indicated that there was a linear decrease in weed dry weights up to

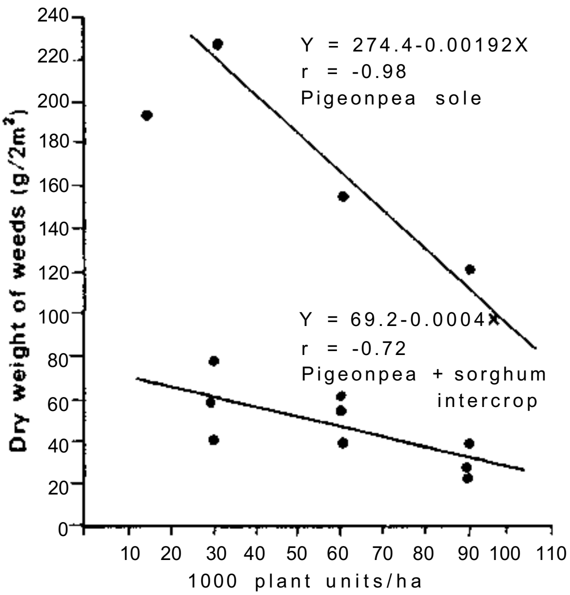

Figure 2. Effect of population pressure on weed growth at ICRISAT Center, 1976. (Source: Rao and Shetty 1976).

90 000 plants/ha in sole pigeonpea and pigeonpea intercropped with sorghum. In the sorghum/pigeonpea intercrop, weed suppression was more evident with increased population of sorghum than of pigeonpea (Shetty and Rao 1979). However, a trend of reduction in weed dry weights was observed when pigeonpea population was increased from half normal to twice normal. That is, weed dry weights decreased as intercropping advantage (LER) increased, due to the suppressing effect of higher plant populations upon weeds (Shetty and Rao 1979).

Effect of Crop Canopy on Weeds

Like any fast-spreading crop species, pigeonpea genotypes that close the canopy rapidly were more successful than other types in competing against weeds. In the compact genotype of pigeonpea (HY-3A) weed growth was 37% higher than that in the spreading variety ST-1 (Table 5). This conclusion was later confirmed at ICRISAT when about 12 cultivars of pigeonpeas of different morphological habit were screened for their competitive ability against weeds. The spreading types, due to their high initial leaf area index, intercept more light than do the compact types, thereby suppressing weeds more successfully (Shetty, unpublished data).

Critical Periods of Crop-Weed Competition

The critical period of crop-weed competition in many annual cereals such as sorghum is the initial 4 to 5 weeks of crop growth (Shetty 1976). But in sorghum/pigeonpea intercropping the period tends to be extended further, indicating that the system should be kept weed-free for at least 7 weeks after sowing to obtain higher productivity per unit area (Shetty and Rao 1977). This is understandable in that the slow-growing and poorly competitive pigeonpea occupies only about 50% of the area, allowing more weed growth. Therefore, though total weed growth is less in intercropping, the weeding operations may have to be extended in order to obtain optimum yields of both the crops.

Table 5. Weed growth in compact vs spreading pigeonpea genotypes with and without sorghum intercrop at 60-day stage after one initial hand weeding at ICRISAT, 1978.

Row spacing	Weed dry weights (g/m^2)* under pigeonpea type				Mean
	Spreading (ST1)		Compact (HY3A)		
	Sole	Intercrop	Sole	Intercrop	
75 cm	156	40	228	36	115,0
150 cm	178	40	240	48	126.5
Mean	167	40	234	42	
Sole vs Intercrop	200.5	41			
Spreading vs Compact	103		138		

Source: Rao and Shetty 1976.
a. Weed dry weights are means of two varieties for each plant type and two replicates; data not analyzed statistically.

Herbicides for Intercropping Systems

Hitherto, research on herbicide use in pigeonpea has been confined mostly to sole cropping, and very little information is available on suitable herbicides for pigeonpea-based intercropping. Trials conducted at ICRISAT indicated that s-triazine herbicides are more promising than others tested on the sorghum/ pigeonpea intercrop system. Ametryn, prometryn, and terbutryn were the safest and most effective herbicides to use (at 1 to 2 kg/ha as preemergence spray) on sorghum/pigeonpea (Shetty and Rao 1977). Fluchloralin (1 to 2 kg/ha preemergence) also performed well, but its selectivity on sorghum needs to be further tested. Band applications of these herbicides on the crop rows, followed by interrow cultivations to control interrow weeds were also tested to minimize the cost of weed control. This method has an added advantage in that different herbicides can be applied separately to different crop rows. In a maize/pigeonpea intercrop, alachlor gave excellent weed control initially, but retarded pigeonpea growth up to 4 months after treatment. However, the crop recovered completely later in the season (ICRISAT 1977). Young et al. (1978) observed that although some progress has been made in identifying herbicides for use in intercrops, compounds that can be used effectively on a broad range of crops are not yet available. Peng and Sze (1967) suggested that the second crop be planted after the residual effects of the herbicide applied to the first crop have diminished, or that two different residual herbicides be applied separately as a band to each of the species in an intercrop. These suggestions may not be practical because of competitive effects of the first crop against the second crop and the difficulty of precise application of herbicides.

Despite some advances in chemical control of weeds in intercropping, the technology has not generally been adopted by farmers. Reasons given include the high cost, the unavailability of recommended herbicides, the difficulties of application, and the supposed availability of inexpensive labor (Moody 1978).

Priorities for Future Weed Research

From the preceding review, it is evident that information on weed management in pigeonpea is meager. No systematic effort has been made to characterize and quantify the nature and magnitude of weed competition in relation to crop age and cropping systems. Weed control schedules should be developed both for sole-crop and intercrop systems involving pigeonpea. The role of weed research should be to identify the best management practices for the newer plant types for different environmental and economic conditions.

Weed research on pigeonpea should be

oriented towards cropping systems as the importance of intercropping in tropical rainfed farming is now recognized. Because weeds are one of the major factors determining the success of a new cropping system, a well-directed strategy is essential for weed management research. Ecophysiological studies leading to the agronomic manipulation of intercropping systems to obtain better management of weeds need to be considered. Some of the questions to be considered in planning research are:

- What are the major weed problems of the system? Does the system encourage the buildup of particular weed species?
- Does the system favor or disfavor weed growth when compared to sole cropping of pigeonpea?
- What are the physical or biological factors operating in the system? Can we manipulate these factors in order to increase the weed-suppressing ability of the system?
- Which management practices affect which weeds and how?
- What is the critical weeding time for sole pigeonpea and intercropped pigeonpea? When, how many times, and for how long a period should the intercrop system be weeded?
- Do intercrops require more labor for weeding? Or do they help alleviate the labor problem?
- What modifications of mechanical weeding are necessary in intercrops? What improved tillage systems need to be developed?
- What is an "acceptable" level of weed competition? Which weeds must be controlled and which weeds could be left alone?
- By continuously practicing the same weed control methods, are we creating conditions that encourage the growth and dominance of certain species? What modifications in the present weeding systems are necessary to avoid this? Can we use crop rotations to avoid problem weeds?
- Can herbicides improve the productivity of the system? Are they economical, at least in the long run? Which herbicides are useful? When and how should these be applied?

Simultaneous research should be done on pigeonpea under sole and intercrop systems. Field trials should be conducted to determine the weed competitiveness of different new cultivars of pigeonpeas. This initial screening process with the breeders would help in selecting only cultivars that are efficient in weed suppression. Another approach is to study the performance of new cultivars under the farmers' present weeding practices, to determine the relative productivity of the systems under farmers' present weed control levels.

It is essential to know exactly what the farmer is doing about weed control in his present system of cropping and to highlight the different weed control requirements of the improved cultivars or improved intercrop system in which pigeonpea is a component. Modifications of the farmers' system and the tools used for weeding or interrow cultivation also need to be determined.

Complete weed control cannot be achieved by using any single method alone. The end result has to be a weed management system that is economical and feasible forthe farmer to use. The broad research objective should be to identify weed management problems and effective measures of weed control through agronomic manipulation. More emphasis should be placed on studies concerning the ecology of major weeds and on obtaining a greater understanding of the biology of each species in association with surrounding plants. Ecophysiological studies to understand *how* the weeds respond and agronomic studies to evaluate *what* should be done to manage them need to be intensified.

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References

ABRAMS, R., and JULIA, F. J. 1974. Effect of mechanical, cultural and chemical weed control on yield and yield components of pigeonpea, *Cajanus cajan* [L.] Millsp. Journal of the Agricultural University of Puerto Rico 58: 466-472.

ANONYMOUS. 1977. Weed control. Pages 128-310 *in* Rubber Research Institute of Malaysia annual research report 1977. Malaysia: RRIM,Kuala Lumpur.

BARNSLEY, G. E., and ROSHER, P. H. 1961. The relationship between the herbicidal effects of 2.6 dichlorobenzonitrile and its persistence in the soil. Weed Research 1(2): 147-158.

DUBEY, P. S. 1973. Phytotoxicity of weeds to crops. 1. Effect on germination. Science and Culture 39(12): 556-558.

GETNER, W. A., and DANIELSON, L. L. 1965. Evaluation of selected herbicides on several pulses. Proceedings, American Society of Horticultural Science 87: 359-362.

HAMMERTON, J. L. 1972. Weed control work in progress at the University of the West Indies. PANS 18(2): 172-182.

ICRISAT. 1977. Agronomy and weed science. Pages 167-177 *in* ICRISAT annual report, 1976-1977, India: ICRISAT, Patancheru, A.P. 502 324.

JURGENS, G. 1972. Weed control in legumes in the Dominican Republic. Presented at the Symposium Arbeitsgruppe Unkrantproblame Warmer Klimate in Arbeitskreis Herbolagie der DPG, 1972, Stuttgart-Holenheim, West Germany.

KASASIAN, L. 1964. Chemical weed control in pigeonpeas. Caribbean Agriculture (Puerto Rico) 2(4): 721-729.

KASASIAN, L. 1971. Weed control in the tropics. London: Leonard Hill. 165 pp.

KASASIAN, L., and SEEYAVE, J. 1969. Chemical weed control in vegetable crops in West Indies. Pages 335-349 in Proceedings, Second Asian Pacific Weed Control Conference Interchange. 16-20 June 1969, College of Agriculture, Laguna, Philippines.

MISRA, K. C, PANDEY, H. N., and MUKHERJI, K. L. 1968. Crop-weed competition for phosphate nutrition. Tropical Ecology 9(2): 243-250.

MOODY, K. 1978. Weed control in intercropping in tropical Asia. Presented at the International Weed Science Conference. International Rice Research Institute, 3-7 July 1978, Los Banos, Philippines.

MOODY, K., and SHETTY, S. V. R. 1979. Weed management in intercropping systems. Presented at the International Workshop on Intercropping. ICRISAT, 10-13 Jan 1979, Hyderabad, India. Proceedings in preparation.

PENG, S. Y., and SZE, W. B. 1967. Preliminary study on chemical weed control in sugarcane intercropped with soybeans and peanuts. Pages 85-87 *in* Proceedings First Asian Pacific Interchange, University of Hawaii, Honolulu, Hawaii, USA.

POONAI, P. 1962. Preliminary experiments with diquat and paraquat in British Guyana. Pesticide Abstracts (C)8(3): 203-209.

RAO, M. R., and SHETTY, S. V. R. 1976. Some biological aspects of intercropping systems on crop weed balance. Indian Journal of Weed Science 9(1): 32-43.

SANKARAN, S., and DAMODARAN, A. 1974. Determination of effective herbicides for weed control in red gram. III. Pages 105-106*in* Tamil Nadu Agricultural University annual report, 1973-74, Coimbatore, India.

SAXENA, M. C, and YADAV, D. S. 1975. Some agronomic considerations of pigeonpeas and chickpeas. Pages 31-62 *in* Proceedings, International Workshop on Grain Legumes, ICRISAT, 13-16 Jan 1975, Hyderabad, India.

SHETTY, S. V. R. 1976. Possible approaches to weed managment in sorghum. Pesticides Information 2(3): 72-80.

SHETTY, S. V. R. 1977. Multi-crop herbicides screening — preliminary evaluation on major SAT crops. Pages 240-241 *in* Proceedings, Weed Science Conference/Workshop. Indian Society of Weed Science, A.P. Agricultural University, Rajendranagar, Hyderabad, India.

SHETTY, S. V. R., and KRANTZ, B. A. 1980. Weed research at ICRISAT. Weed Science. 28(4): 451-454.

SHETTY, S. V. R., and RAO, M. R. 1977. Weed management studies in pigeonpea based intercropping. Pages 655-673 *in* Proceedings, Sixth Asian Pacific Weed Science Society Conference. Jakarta, Indonesia.

SHETTY, S. V. R., and RAO, A. N. 1979. Weed management studies in sorghum/pigeonpea and pearl millet/groundnut intercrop systems — some observations. Presented at the International Workshop on Intercropping, ICRISAT, 10-13 Jan 1979, Hyderabad, India. Proceedings in preparation.

SINGH, R. C., and FARODA, A. S. 1977. Weed control in pigeonpea. Indian Journal of Weed Science 9(1): 38-42.

WALLIS, E. S., WHITEMAN, P. C, and AKINOLA, J. 0. 1975. Pigeonpea research in Australia. Pages 149-167 *in* Proceedings, International Workshop on Grain Legumes. ICRISAT, 13-16 Jan 1975, Hyderabd, India.

YOUNG, D., MILLER, S., FISHER, H., and SHIEK, M. 1978. Selecting appropriate weed control systems for developing countries. Weed Science 26: 209-212.

Discussion — Session 4

Tahiliani:

In middle Gujarat, cultivators are replacing cotton with sole pigeonpea. Fields show about 50% wilt-infected plants. Can we get wilt-resistant seed for demonstration trials in farmers' fields?

Nene:

We will be happy to supply a few seeds of resistant lines on request.

Mehta:

In field screening against the three major diseases of pigeonpea, have you observed interaction between any two or all three? In what parts of India is *Uredo cajani* found?

Nene:

We have not observed any interaction between the diseases under reference. *Uredo cajani* has been reported from Bihar state; in addition, we have occasionally observed a few pustules on old leaves at ICRISAT Center.

B. M. Sharma:

Is there any chemical to control sterility mosaic? Incidenceof thisdisease is increasing to alarming proportions, spreading from Bihar to Uttar Pradesh.

Nene:

If plants are protected with sprays of an insecticide such as endosulfan, which also kills mites, up to 45 days after sowing, sterility mosaic can be very effectively controlled. I would add, however, that resistant lines are available and seed of these should be made available on a large scale.

van Emden:

Your observation of insecticidal control of sterility mosaic may indicate that the eriophyid mites spread by being picked up on the hairs of insect legs. Have you ruled out this possibility?

Nene:

We have no reason to suspect that the vector mite is being spread by insects. We have been able to pick up mites on sticky plates and therefore feel that the wind spreads the mites.

Wallis:

Are nematodes an important production limit in any cropping system of pigeonpea? Are there any pathological associations or resistance known?

Nene:

Nematode cysts (*Heterodera cajani)* are present even in wilt-sick plots, but we have found no association with wilt incidence.

Saka:

Did Dr. J. L. Starr conduct any *Fusarium-Heterodera* complex studies on your resistant materials? This complex has been identified in Malawi. We plan to do this work on your materials because of the many races of root-knot nematodes.

Nene:

Root-knot is not much of a problem in pigeonpeas in semi-arid regions. Dr. Starr did look into the possibility of *Heterodera-Fusarium* interaction but failed to find any. We will be interested in your work on this.

Joshi:

It is important to study the genetics of resistance to major pathogens, especially if we wish to pyramid genes to obtain multiple resistance. What stage has this work reached? In studying resistance to such soilborne pathogens as *Phytophthora* and *Fusarium,* a technique used with great success in Egypt is to culture spores on root exudates of susceptible and resistant genotypes. Spores do not germinate on the resistant exudates. The advantage of this technique is that you can use it all year round in the laboratory.

Nene:

Work on inheritance of resistance has been initiated. We appreciate your suggestion and will certainly consider it.

Byth:

Choice of parents is a problem in quantitative breeding, further complicated by regional differences in the importance of a disease. Is there any evidence of association of deleterious (or favorable) characters with genes conditioning disease resistance, which might complicate decisions on choice of parentage?

Nene:

We have yet to obtain information on this aspect.

Joshi:

I have three comments on weed management:

1. Chemical herbicides, mostly oil-based, are too expensive for rainfed farming.
2. Quick-growing and quick-spreading "smother" crops are important for controlling weeds, but they should not climb on to and smother the main crop. Smother crops should be identified for both seed and fodder value.
3. Mulching is very helpful in suppressing weeds and conserving soil moisture. This aspect should be given greater emphasis in weed control.

Shetty:

We at ICRISAT have not yet done much with mulching, but we are aware of its importance and its role in moisture conservation and weed control. We did conduct a trial a few years ago to determine the effect of kharif stubble mulching on the yields of rabi-planted chickpea. The dead weeds and kharif stubble, when left in situ, significantly increased chickpea yields.

Ramanujam:

Several cowpea genotypes besides C-152 are now available. Also several mung and urd bean genotypes have been identified for such parallel (smother) cropping.

Nema:

Cyperus and *Cyanodon* are noxious weeds in Madhya Pradesh. Have you any recommendation for their control?

Shetty:

Herbicides such as glyphosate, or Roundup, are effective on these weeds, but are very expensive. A combination of mechanical, chemical, biological (crop competition), and cultural methods should help manage these weeds. We have not developed any recommendations but we have found that these weeds are highly shade-sensitive and therefore the role of the crop canopy in controlling them should be recognized.

Kayande:

Striga is a serious weed in sorghum, particularly under moisture stress. What are the methods by which *Striga* could be controlled? Is there any effect of sorghum/pigeonpea intercropping on the *Striga* population?

Shetty:

We have not had much experience with *Striga,* but at present much of the work revolves around breeding for *Striga* tolerance. ICRISAT breeders have made some progress in this direction. There are no effective preemergence herbicides to control *Striga;* 2, 4-D postemergence can only prevent further multiplication. "Catch" and "trap" crops are also now becoming popular. We are not aware of any intercropping effect on *Striga* emergence. I agree it is worth observing.

Session 5

Physiology and Microbiology

Chairman: E. H. Roberts

Rapporteurs: N. P. Saxena
J. V. D. K. Kumar Rao

The Potential Contribution of Physiological Research to Pigeonpea Improvement

R. J. Lawn*

Abstract

The potential for significant contribution by physiological research to pigeonpea improvement lies in the development of a comprehensive understanding of the ecophysiological basis of adaptation of the crop. There is a clear need to elucidate the role of environmental factors, particularly the interaction of day length and temperature, in the control of rate of ontogenetic development during all phases. At the same time there is need to delineate the range of response types available and the extent of G x E interaction. Such research will enable the prediction of plant phenology in particular environments and facilitate the matching of phenology so as to minimize the impact of potential constraints of the environment. It will also assist in obtaining more rapid generation turnover in breeding.

There is also clear need to identify environmental factors that are major constraints to growth and partitioning in pigeonpea, and to develop, in collaboration with relevant disciplines, an understanding of the physiological basis of response to those factors. The range of potential response types and the extent of G x E interaction should be delineated as a prelude to future breeding activity. Two factors that warrant particular attention in this context are temperature and water.

To contribute to the overall process of plant improvement, physiological research must be conducted with an awareness of G x E interaction. Unfortunately a substantial body of literature exists of research into the interrelationships between various physiological processes without any apparent understanding that one or more of the processes under investigation is sensitive to G x E interaction, and that the results are therefore site or genotype specific, or both.

This paper first briefly discusses how, in general terms, physiological research might contribute to crop improvement. Itthen outlines a number of areas where potential exists for specific contribution by physiological research to pigeonpea improvement in the short term. Strong reliance is placed on relevant knowledge and experience generated from improvement programs in other pulses to illustrate this potential.

Physiological research may be basic or applied, although in practice it is sometimes difficult to clearly differentiate the two. By implication, applied research is more closely oriented to the short-term problems confronting crop improvement. The greatest potential for contribution by physiology to plant improvement lies in the integration of applied physiological research with that in related disciplines.

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The Role of Physiological Research in Crop Improvement

In general terms, crop improvement seeks to optimize the use of production resou rces in two ways:

1. by manipulation of genetic material to optimize production relative to the constraints imposed by the environment, and

2. by manipulation of the environment to optimize production relative to the constraints imposed by available genetic material.

Usually, both processes operate simultaneously. The former involves selection and plant breeding; the latter, changes in agronomic practice. Implicit in both processes is the expectation of variation in plant performance between, respectively, different genotypes and different environments. Without that variation, no potential for improvement can exist.

The potential rate of improvement from the selection/breeding process compared with that from changing agronomic practice depends on both the plant species and its history of use. Breeding potential will be influenced in part by the variability available and the efficiency of selection procedures used. Agronomic potential will depend on the degree to which current practice allows the expression of the genetic potential of existing cultivars, and to which current environmental constraints can be economically ameliorated by changing cultural practices. The actual rate of improvement will depend on the degree to which both agronomic and breeding potential are tempered by other social and economic factors.

A brief survey of the range of grain legume yields indicates a wide gap between actual and potential yields in most species (Table 1). The magnitude of the gap indicates that there is scope in many of these crops for short-term gains through improved cultural practice, notwithstanding the acknowledged severity of disease and pest problems. It is surprising, therefore, that much current thinking on the role of physiological research in grain legume improvement concentrates rather precariously on the plant breeder, often ignoring the potential for varying cultural practices (e.g. Summerfield and Wien 1980). Certainly in pigeonpea there appears scope for yield improvement in the short term through changes in agronomic practice (Byth et al. these Proceedings; Wallis et al. 1979).

Table 1. Comparison of actual and potential yields (kg/ha) of six grain legumes.

	World average	Highest national average	Maximum experimental yield
Chickpea	590	1724	4000-5000
Cowpea	212	3457	3500-4000
Dry beans	535	2374	4000-5000
Groundnut (in shell)	986	3846	6000-7000
Soybean	1471	3000	5000-6000
Pigeonpea	699	2194	4000-5000

Sources: World average and highest national average from FAO Production Year Book; maximum experimental yields based on various literature reports.

Optimization of genetic potential and/or agronomic practice could be approached by trial and error. Indeed, such has been the basis for the development of many of man's plant production systems from antiquity. This approach is inefficient in the use of time and resources if both genotype and environment are to be simultaneously optimized, particularly given an expectation of genotype x environment (G x E) interaction. Alternatively, a knowledge of plant function can be used to predict plant performance in particular environments, making it feasible to eliminate in advance many of the errors in the trial-and-error approach. Obviously, the gain in efficiency depends on the accuracy of prediction, which in turn depends on the soundness of the knowledge of plant function.

A knowledge of plant physiological function, however, is not a prerequisite to the successful prediction of plant performance; plant breeders have made substantial progress in this same direction. Indeed, they have been known to complain, not unjustifiably, that much physiology is really post-facto analysis of what they have already achieved often using genetic predictors. Genetic predictive techniques, however, are limited in their prediction of performance in specific environments, particularly where large but nonsystematic G x E interaction is involved.

In contrast to the genetic techniques, prediction techniques based on physiological knowledge may enable the prediction of performance of specific genotypes in particular environments for those functions subject to G x E. The approach requires the measurement of specific physiological attributes of the genetic material and specific ecological attributes of the environment. Then, provided the relationships between those physiological processes and the environmental attributes are known, it becomes possible to predict a priori plant performance in that environment. As in the case of genetic prediction techniques, the expectations of physiological function must at some stagebetested.Theadvantage, however, is that once an understanding is gained, only specific attributes of both the genetic material and the environment need then be measured for making successful predictions. This may enable a substantial saving in resources over what would be required to test all thegenetic material in each potential environment (or potential environmental manipulation). Further, greater precision of measurement of both plant and environment is possible because of the focus on specific, defined attributes.

It is a theme of this paper that in conceptual terms the most significant potential for contribution by physiology to pigeonpea improvement lies in developing an understanding of the ecophysiological basis of G x E interaction for various plant functions in the crop. Much of the subsequent discussion is therefore devoted to an attempt to exemplify how this potential might be realized in practical terms. This is not to suggest, however, that the ecophysiological approach is the only direction to take; merely that it is applicable to those plant functions likely to be of most significance. Those plant functions that are (at least in practical terms) either ubiquitous among genotypes (e.g. photosynthetic pathway) or environmentally insensitive (e.g. certain morphological traits) may well be studied outside the context of genotypic or environmental variation. But the general point is made that, unlike the potential advantage of the ecophysiological approach over conventional genetic techniques, that is, in the analysis of G x E, there is little inherent advantage of such physiological research over traditional breeding approaches. Rather, it represents an alternative approach.

For example, in the case of plant characters that are genetically variable but show little environmental sensitivity (e.g. leaf size or shape), the main contribution of applied physiological research is in the initial recognition of the superior functional type, which then provides the breeder with a selection criterion. Obviously, it is one area where post-facto physiological analysis of the breeder's achievement offers littlefor plant improvement. In the reverse case, where genetic variation is nonexistent, the only scope for improvement lies in environmental manipulation. Where there is neither genetic nor environmental variation, there is no potential for improvement and so no place for the study of that function in applied physiological research.

It follows that to make an effective contribution to the plant improvement process, physiological research into plant functions that are subject to G x E interaction must take G x E into account. Otherwise its utility to the broader process of plant improvement is limited to the very germplasm or environmental situation wherein the research was done. Thus it can be recognized as little more than another trial in the trial-and-error method of plant improvement. As such, it should not be masqueraded as applied physiological research. Rather, it is work that has been and continues to be done most effectively by farmers, who do not expect to be paid a salary for their research work.

Ecophysiology

Goals of Ecophysiology

In summary the requirements of ecophysiology are threefold:

1. The identification of physiological processes that condition changes in plant performance in response to the environment, and the definition of attributes which effectively and efficiently characterize those processes.
2. The identification of ecological factors that condition changes in plant performance by their impact on plant function, and the definition of specific attributes that effectively and efficiently characterize those factors.
3. The development of an understanding, in quantitative terms, of both the function of those specific physiological processes in relation to the requisite environmental factors and of the consequences for plant performance of their interaction with other physiological processes.

The third requirement provides the basis for quantitative analysis of G x E interaction and is the very essence of applied physiological research. It is the most difficult to fulfill.

Overall plant function can be viewed as the integral of three primary processes:

- ontogenetic development
- growth (dry matter accumulation, nitrogen fixation, nutrient uptake)
- assimilate partitioning

Each of these three processes is closely interdependent on the others and each is responsive to variation in a range of environmental factors, although not necessarily with the same sensitivity or even to the same factors. Evidence from both pigeonpea and other pulses indicates that ecological factors that are of adaptive significance include three types:

1. climatic (e.g. temperature, daylength, radiation, rainfall, humidity),
2 edaphic (e.g. soil fertility, pH, water-holding capacity), and
1 biotic (e.g. pests, diseases, soil *Rhizobium* populations, competitive influences of weeds, companion crops, and neighbors).

It is beyond the scope of this paper to attempt a comprehensive review of the knowledge available on the interrelationships between those physiological processes and the various ecological factors. Rather, some of the more important aspects will be discussed in an attempt to exemplify the potential contribution of physiological research to pigeonpea improvement.

Ontogeny

The rate of ontogenetic development and hence crop phenology is influenced both genetically and environmentally in a range of pulses with daylength, temperature and water availability three of the most common environmental factors involved. Pigeonpea is a short lived perennial species with extremely variable phenology depending on cultivar and sowing time. There is virtually continuous variation in flowering time among cultivars for sowings made prior to the longest days of the year from about 60 days to more than 200 days (Green et al. 1979). For sowings made after the longest days, the rate of development is progressively more rapid so that most cultivars become earlier flowering (Fig. 1) Although cultivar maturity

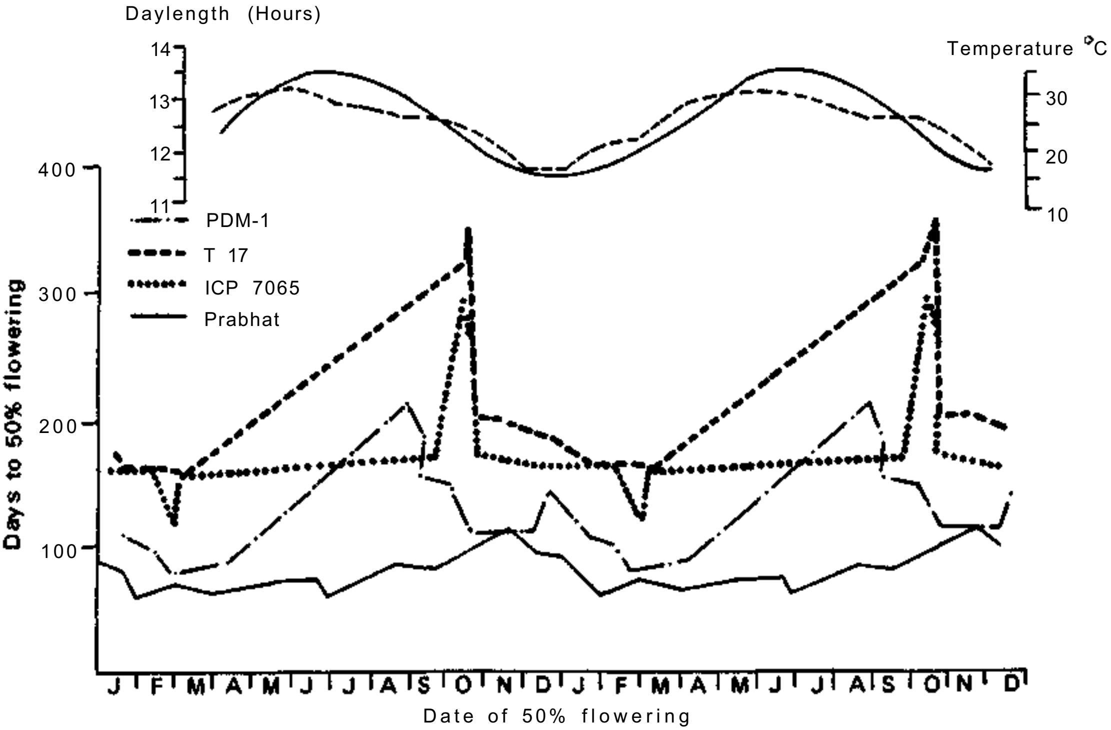


Figure 1a. Variation in days to flowering plotted against date of flowering for a range of sowings of pigeonpea genotypes of differing maturity (a) Green et al. 1979.

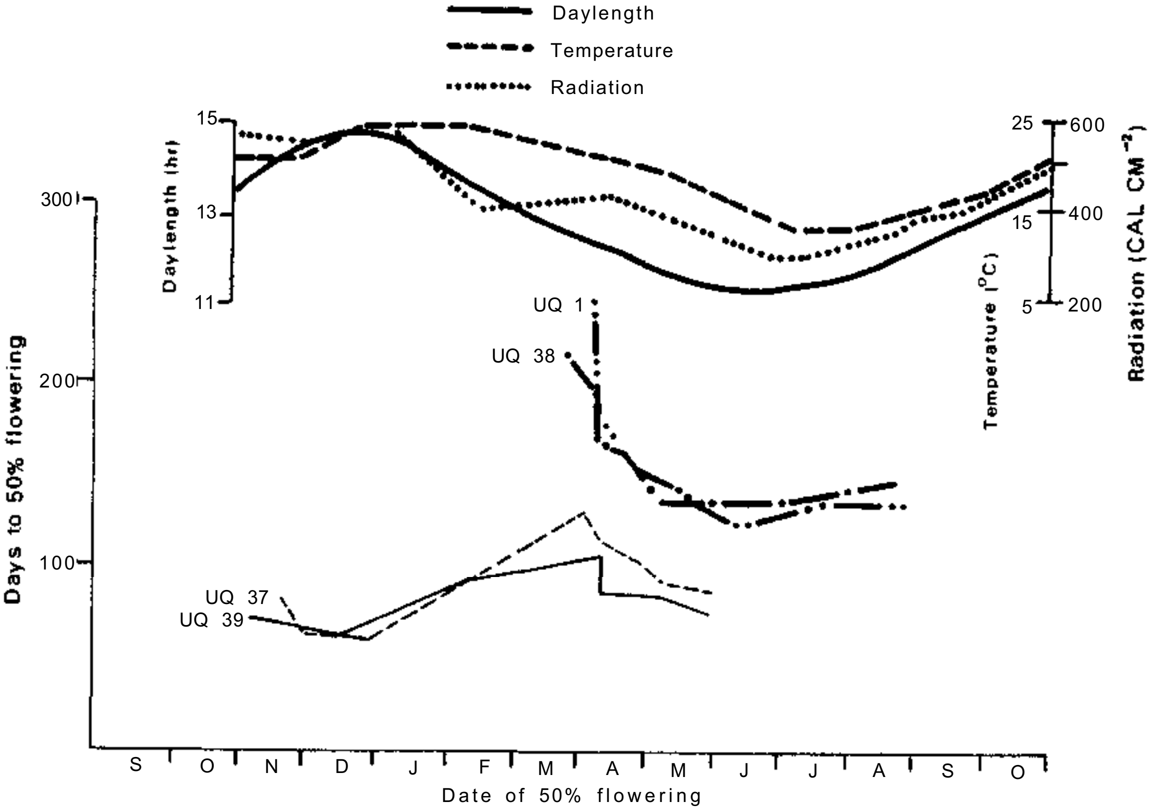


Figure 1b. Variation in days to flowering plotted against date of flowering for a range of sowings of pigeonpea genotypes of differing maturity {bj Akinola and Whiteman 1975.

ranking tends to remain the same, the increase in rate of development is generally more pronounced in the later maturing cultivars.

The field evidence is consistent with quantitative short day response which is *common* to many tropical pulses, e.g. soybeans (Byth 1968) cowpeas (Summerfield 1977), and various species of the Asiatic *Vigna* group (Aggarwal and Poehlman 1977, Lawn 1979a). In these plants, the rate of development increases with shorter daylengths, at least over that daylength range for which sensitivity exists. Generally later maturing cultivars are sensitive to shorter daylengths than earlier maturing cultivars (Byth 1968). Most developmental phases are potentially daylength sensitive (*cf* Johnson, Borthwick, and Leffel, 1960; Lawn and Byth 1979). Differential sensitivity exists among cultivars, and in soybean several reports have been made of absolute day neutrality for time to flowering (Criswell and Hume 1972; Poison 1972). Differential sensitivity may also exist between ontogenetic phases within cultivars (Lawn 1979a, Lawn and Byth 1973). In pigeonpea, controlled environment studies in New Zealand (McPherson and Warrington personal communication 1980) and at the University of Queensland (Turnbull et al., these Proceedings) support the field evidence for quantitative short-day response in many lines. The existence of absolute day-neutral types in relation to time to flowering is also reported for pigeonpea (Turnbull et al., these Proceedings).

The rate of ontogenetic development in pulses is generally sensitive to temperature (e.g. see review, Summerfield and Wien 1980). Generally, the effect of temperature on development rate in quantitative short day plants is for cooler temperatures to slow development and thus offset the effect of shorter daylengths.

However, complex temperature *x* daylength interactions can occur between cultivars, and possibly between stages of development within cultivars, although the latter remains to be critically tested.

Variation in nighttemperatures as opposed to day temperatures has been emphasized (Summerfield et al. 1978) as being most important in conditioning response to temperature. Recent studies suggest that this may be an oversimplification, however, and an artifact of a narrow range of germplasm and environmental factors under test. In soybeans (Tanner and Hume 1975; Lawn and Byth unpublished data) and urd bean and mung bean (Lawn 1979a), there is evidence that genotypes of temperate/subtropical origin may be more responsive to day temperatures and those of tropical origin more sensitive to night temperatures. Even these results may reflect the particular range of temperatures under test, and it may well turn out, for example, that thermoperiodism exists in some short-day pulses. That is, there may be an "optimum" day and "optimum" night temperature, with variation among cultivars for both. In that situation, the magnitude of the response to variation in day versus night temperatures would depend on the relative magnitude of the deviation of both from the respective optima, as well as any differential sensitivity to either day or nighttemperature. This point remains to be critically tested.

In pigeonpea there is field evidence that cooler temperatures slow development during various phases (Akinola and Whiteman 1975). This is supported by controlled environment work wherein flowering of 11 cultivars was delayed by 1 to 28 days when mean daily temperature was reduced from 24° to 20°C (McPherson and Warrington, personal communication, 1980). However, raising mean daily temperature by 4° to 28°C, also delayed flowering by 2 to 42 days. Controlled environment studies at the University of Queensland have also proved enigmatic in that for several early-flowering lines, cooler temperatures induced earlier initiation, but delayed the subsequent development of floral buds (Turnbull et al., these Proceedings). Field observation at Mahabaleshwar, Maharashtra (17°N, 2000 m) indicated that under long-day conditions, low temperatures promoted flowering in normally short-day genotypes (ICRISAT 1976).

Phenology may also be influenced by availability of soil water, particularly in indeterminate pulses (Angus et al. 1979; Turk et al. 1980). In cowpea, for example, moderate stress has been found to induce earlier flowering, while severe stress may delay flowering. In field studies in southeast Queensland, the most dramatic effect of water stress in three *Vigna* species has been on the expression of indeterminance (Lawn unpublished data). In urd bean, mung bean, and cowpea, the duration of both the flowering and flowering to maturity phases was substantially reduced by stress. It seems probable that availability of soil water will prove of significance in the expression of indeterminance, and perenniality in ratooning situations in pigeonpea. Various physical and biotic factors that act to disrupt seed set may also influence expression of determinance. In particular, pod and flower removal stimulates new flushes of flowering and delays maturity in many pulses.

Growth and Partitioning

There is an initial lag phase in dry matter (DM) accumulation in pigeonpea of 30 to 85 days (Sheldrake and Narayanan 1979; Wallis et al. 1975). Net assimilation rates during this phase appear to be as high as in any phase of growth (Sheldrake and Narayanan 1979), indicating that the lag phase may be due to relatively slow leaf area accumulation. In turn this may reflect an initial high investment in root development. After the lag phase, growth rates increase with increasing leaf area, reach a maximum, and subsequently decline. Branch development occurs freely in spaced plants of most cultivars.

In indeterminate cultivars, continued node growth after floral initiation may account for a large proportion of total nodes accumulated. Even in determinate cultivars, continued stem DM accumulation occurs after flowering, primarily through growth of branches. Leaf DM may reach a maximum at various ontogenetic stages ranging from early flowering to pod filling, depending on when the rate of new leaf growth is balanced by senescence of old leaf. Leaf senescence appears to depend partly on both leaf age and degree of shading, so that the ontogenetic stage when senescence begins depends in turn on crop duration and sowing density. Regardless of crop duration, leaf DM declines during late pod filling, as remobilization of assimilates occurs from senescent leaf into developing seed. Stem DM may also decline during pod filling. Net assimilation rates (NAR) in pigeonpea may increase during pod filling, perhaps due to photosynthesis by stems and pod walls (Sheldrake and Narayanan 1979). The NAR increase may also reflect the loss of photosynthetically inefficient lower senescent leaf.

Pigeonpea is comparatively deep rooted and is therefore capable of utilizing stored soil water at depth; more than 150 cm, for example, in a long-duration cultivar (Sheldrake and Narayanan 1979). Seasonal variation in nodule weight per plant paralleled plant DM accumulation, with an initial lag phase (Wall is et al. 1975). There is some suggestion that nodule cycling may exist in long-duration cultivars with wide fluctuation in numbers during the season (Sheldrake and Narayanan 1979). Most nodules were found in the top 20 cm of soil, although occasional nodules were recovered from the extraordinary depth of 120 cm. During late pod filling, nodules invariably senesced.

Overall crop growth rate can be expressed as a function of the amount of radiation reaching the crop surface, the efficiency of its interception by the crop, and the efficiency of its conversion to DM (Monteith 1972). Grain yield in turn depends on the harvest index (HI) or efficiency of partitioning of DM. Little can be done about the amount of light reaching the crop surface apart from matching the timing of the crop with seasonal variations in radiation level. In the case of the other functions, however, there is substantial scope for improvement in the pulses.

The efficiency of radiation interception by the crop is largely a function of leaf area index (LAI), the relationship being virtually linear up to full light interception (Shibles and Weber 1965, 1966; Wallis et al. 1975). Beyond this point, further leaf area development is excessive to the requirements for full interception and therefore to maximum crop growth rate unless changes in canopy structure ensure light is distributed evenly over the increased leaf area. The slope of the linear phase of the interception — LAI curve, and hence the LAI needed for light interception, or "critical" LAI (Shibles and Weber 1966) — depends on the absorption characteristics of the canopy, which in turn are afunction of factors such as leaf size, shape, angle, etc. The critical LAI also depends on incident radiation level. In spaced plantings of a long-season cultivar, critical LAI values for pigeonpea were around 6 (Wallis et al. 1975). In order to maximize crop growth rate during pod filling, it follows that full light interception (i.e., canopy closure) should have occurred by that stage. To the extent that closure is not achieved during reproductive growth, potential productivity is limited. On the other hand, where leaf area accumulation in excess of the critical LAI continues during pod filling, the extra vegetative growth represents assimilates that might well be directly partitioned into grain.

Given the low LAI of pigeonpea during the early vegetative phase, efficiency of radiation interception is very low compared with other pulses, e.g., soybean, cowpea, and mung bean. This is of less significance in intercropping, where the leaf area development of the companion crop may compensate and contribute to high overall canopy efficiency (Sheldrake and Narayanan 1979). However, in monocrops the lag phase in pigeonpea has implications both for short-duration cropping and early suppression of weeds.

The efficiency of utilization of intercepted radiation is influenced both genetically (e.g. through canopy absorption characteristics that influence distribution of light over the leaf surface, and photosynthetic rates) and environmentally (through a range of potential rate-limiting factors such as temperature, water stress, waterlogging, and nutrition). Evidence from other pulses, particularly soybean suggests there is greater potential for improvement in the short term in relation to the environmental, rather than the genetic, limitations to efficiency of light utilization.

The effect of temperature on various aspects of growth in pulses has been recently reviewed (Summerfield and Wien 1980). Germination, root and shoot growth, nodulation, nitrogen fixation, flower and pod set, formation of viable pollen, and seed quality are all sensitive to temperature. Much of the research emphasis on the effects of temperature has been on plant response to temperature extremes, e.g. frosts, heat waves, etc., with attempts to select for genotypes more tolerant of the extremes (Emerson and Minor 1979; Hume and Jackson 1980a, 1980b).

Recently, variation among genotypes in sensitivity of growth to temperature was reported in several species of the Asiatic *Vigna* group (Lawn 1979b). In general, sensitivity to temperature was inversely correlated with latitude of origin of some 16 genotypes tested, indicating that the differential sensitivity was of adaptive significance. In this study, sensitivity in terms of vegetative DM growth rate was correlated with yield growth rate. However, sensitivity to temperature in one growth process does not necessarily correlate well with that in another (Hume and Jackson 1980a, 1980b). In pigeonpea there is evidence that overall growth rate is influenced by temperature, with slower rates for winter (rabi) crops (Akinola and Whiteman 1975; Hughes et al. 1980; Sheldrake and Narayanan 1979).

Availability of water is one ecological factor of major adaptive significance to a long-duration crop such as pigeonpea, where part or all of the growth cycle may occur during periods of low rainfall probability. Water stress affects virtually all aspects of plant growth; however, differential sensitivity of growth stages has led to the concept of critical stages (Shaw and Laing 1966). Generally, in terms of seed yield, pulses are most sensitive during the late flowering and early pod-filling stages. The effect of water stress on particular processes may be either a direct physiological consequence of dehydration or an indirect effect arising from reduced assimilate supply. In terms of N_2 fixation, for example, there is evidence of both a direct dehydration effect on nodules (Sprent 1976) and of an indirect effect through reduced assimilate supply (Huang et al. 1975). Various reports discuss the effect of water stress on plant photosynthesis (Rawson and Constable, these Proceedings) and on efficiency of light utilization by the pigeonpea canopy (Hughes et al. 1980).

Knowledge on acclimatization of pulses to water stress is generally limited. Recent studies in southeastern Queensland have shown, however, that there is a range of mechanisms whereby pulses respond to stress (Lawn, unpublished data). These include dehydration avoidance, whereby plants maintain leaf water potential (LWP) by stomatat closure, adjustment or phenology, adjustment of leaf area either through senescence of older leaf or variation in the rate of production of new leaf, and leaf movement. Cowpea is a "water-saver," with stomatal closure occurring at comparatively high LWP after relatively little water loss. At the other extreme, soybean is a "water-spender," with LWP falling to comparatively low levels before stomata completely close. Urd bean and mung bean are intermediate in response. Variation in other plant growth characteristics complements these responses. For example, soybean may continue to accumulate DM after the onset of stress, while growth in cowpea may slow substantially.

Diaheliotropy occurs in pigeonpea, soybean, urd, mung, and cowpea under irrigation. Under stress, the three *Vigna* species show strong paraheliotropy; i.e., the plane of the leaf surface is oriented along the direction of the sun's rays, thus minimizing radiation interception. In part, this response appears to amelioratethe effect of stomatal closure on leaf temperature. Stressed soybean leaves, however, wilt and show minimal paraheliotropy, perhaps because of the lower LWP developed, and therefore lower turgor. The *Vigna* spp. show phenology adjustment in response to stress, particularly green gram which under severe stress acts almost like an ephemeral plant. Soil water use reflects the various stress adjustment responses, extraction being in order soybean > black gram > cowpea > green gram.

The extent of these adjustment mechanisms in pigeonpea has yet to be measured. One observation of potential significance in pigeonpea, however, is the recent recognition that relative to other pulses, substantial adjustment in osmotic potential (OP) can occur in response to stress (M. M. Ludlow and R. C. Muchow 1979, unpublished data). Osmotic adjustment is the lowering of leaf OP (measured at full turgor, 100% RWC) caused by the accumulation of solutes such as ions, sugars, and organic acids. The decrease in OP wholly or partially offsets the decline in LWP that occurs during stress and assists the maintenance of positive turgor. Thus osmotic adjustment delays the cessation of turgor-driven processes such as leaf expansion, stomatal opening, root growth, and many metabolic processes. Osmotic adjustment may therefore have major implications for continued root growth after the onset of stress, and therefore for soil water exploitation in dryland pigeonpea. Variation for osmotic adjustment exists within the pigeonpea lines so far tested. For example, it is low in the University of Queensland day-length-insehsitive line and cv Royes, but high in the long-duration cultivar ICP-7035.

The agronomic significance of water stress adjustment mechanisms in pulses remains to be determined. Preliminary data, however, suggest that several have major implications for water, carbon, and nitrogen balance, and will prove of importance in adaptation to particular stress environments.

A clear picture has yet to emerge of the interrelationship between ecological factors and partitioning of DM into grain in the pulses, primarily because of their physiological indeterminance and the consequent difficulty of integrating response to specific factors over time. Generally, many more reproductive structures are initiated than are ever developed to maturity, even in apparently ideal conditions. Thus substantial yield homeostasis is possible in relation to stresses (e.g. heat waves, water stress, cold, insects) occurring at a particular time (see Shaw and Laing 1966). Both daylength and temperature influence the partitioning of DM into reproductive versus vegetative growth in short-day pulses, partly through an effect on sink formation and sink retention, and partly through a direct effect on expression of indeterminance. Field data (van Schaik and Probst 1958) and controlled environment studies (Fisher 1963) indicate that in soybeans long daylengths reduce flower set as do high (Green et al. 1965) and low (Hume and Jackson 1980b) temperatures. The effect of daylength on expression of indeterminance is more subtle. As early as 1923 it was reported that u nder shorter daylengths, more DM was partitioned into seed (Garner and Allard 1923). Likewise in controlled environment studies, it has been demonstrated that the proportion of DM produced after flowering to be partitioned into seed depended on the daylength to which plants were subsequently exposed (Johnson et al. 1960). Again, reproductive DM accumulation was favored by shorter daylengths.

Field studies with a number of short-day species suggest that in general, Hi is highest when cultivars are grown in daylengths that are short relative to the range over which they are quantitatively sensitive. Thus HI in soybeans (Lawn and Byth 1974) and several *Vigna* spp. (Lawn 1979b) was highest in cultivars that were early maturing at the test latitude. Similarly, HI increased as sowings were delayed into shorter daylengths, in some cases by as much as fourfold. Field studies in pigeonpea suggest similar responses, at least in respect to sowing date. For example HI for four accessions was low (~0.20) for sowings prior to the summer solstice, and peaked (~0.50) for sowings in January (Akinola and Whiteman 1975). Likewise, ICRISAT data indicate HI is higher for rabi sowings of most cultivars (Sheldrake and Narayanan 1979). Limited field data from sowing date studies, however, indicate that short daylengths notwithstanding, low temperatures reduce HI (Akinola and Whiteman 1975; Lawn 1979b; Lawn and Byth 1974).

Applications of Ecophysiological Research in Pigeonpea Improvement

Phenology Prediction

The most significant contribution to be made to pigeonpea improvement in the shortterm is the prediction of crop phenology in particular environments, a process aided by the fact that the two main environmental determinants of the rate of ontogenetic development are themselves largely predictable across locations. Daylength varies regularly with latitude and time of year, while seasonal profiles of temperature can be predicted within acceptable limits from meteorological records. In some cases, rather simple predictions of phenological response are possible, based solely on cultivar response to a number of environments differing only in daylength and temperature. For example, based on phenological response of soybeans to sowing date at latitude 27°S (Lawn and Byth 1973), it was possible to anticipate response at 17°S (Beech et al. 1979). Empirical mathematical models that account for photoperiod x temperature interactions can provide a more sophisticated and accurate approach (Franquin 1974; Major et al. 1975; Robertson 1968). Initial information indicates that control of development in pigeonpea is complex, so that at best, sophisticated modeling approaches will be necessary. The potential benefits, however, are large.

A knowledge of the control of phenology can be used to streamline the breeding program.

either through synchrony of flowering or through more rapid generation turnover (Byth and Lawn 1971; Lawn and Byth 1979). Synchrony of flowering to facilitate hybridization has particular significance in a phenologically variable crop such as pigeonpea, while accelerated generation turnover is critical if rapid genetic advance is to be possible in long-duration pigeonpeas (Byth et al. these Proceedings). A knowledge of phenology itself is of relevance in generating information on potential adaptation of genotypes to specific environments and appropriate agronomic practices.

Adapting Pigeonpea to the Environment

The ability to predict phenology facilitates the matching of the crop with the major constraints of the environment, i.e., to match the periods wheretemperature, radiation, and watersupply are adequate for crop growth. It also aids in the discrimination of those sets of germplasm relevant for test in specific environments, in the choice of optimal sowing times, and in some cases, inthe defining of new optimal production systems (Wallis et al., these Proceedings).

The U.S. soybean maturity group classification is an historic example of a simple but successful system for matching the phenology of cultivars with duration of arable temperatures over latitude. The full potential of that system was not exploited, however, because of the inflexibility arising from the initial adherence of U.S. soybean producers to wide-row culture as traditionally used in other crops. Wide rows necessitated long-duration crops in order to fully exploit the interrow space available so that early sowings and late-maturing cultivars were necessary within each zone to optimize yields. Therefore, the zone of potential adaptation for particular cultivars was narrower than if the agronomy used, had been more flexible, and yield losses were inevitable when seasonal conditions delayed sowing (Cooper 1979).

There may, of course, have been very valid reasons for the adherence to wide rows; for instance, existing machinery or the difficulty of weed control in narrow rows. However, whenever additional constraints relating to cultural practice are placed on the production system, there is some loss of both flexibility and overall efficiency. Those involved in crop improvement must therefore seek to evaluate the biological potential of various options, so that decisions on practical production systems may then be made in circumstances where the technical, social, and economic constraints can be adequately evaluated and costed.

Successful matching of crop and environment may involve more than simply matching durations, since, as discussed earlier, many aspects of plant function show differential sensitivity to environmental factors, depending on the ontogenetic stage of development of the crop. For example, it is possible to reverse the relative yield performance of soybean cultivars merely by selective timing of stress (Lawn et al. 1977).

Optimizing Cultural Practices

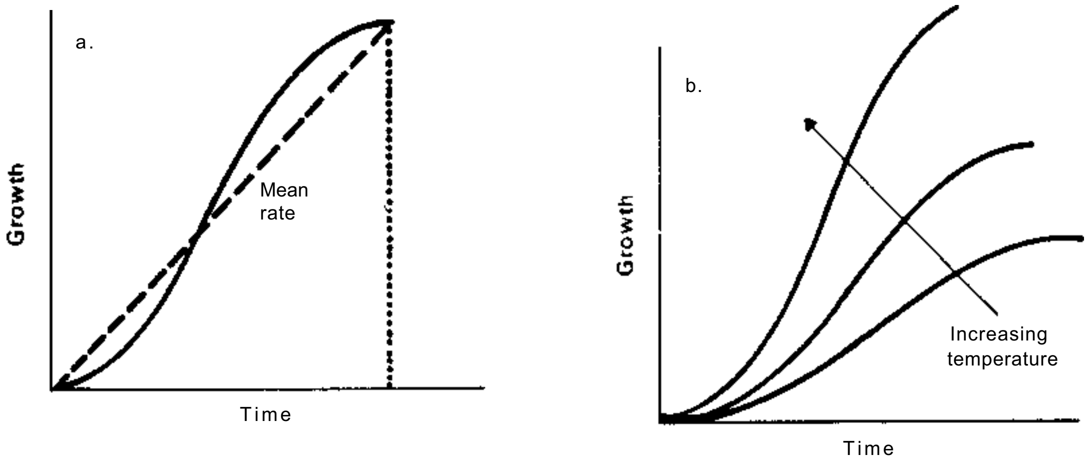
Certain cultural practices such as planting arrangement, row spacing, and sowing density are influenced by expectations of plant size. To the extent that predictions of plant (and crop) growth can be improved, such cultural practices can be optimized. Overall growth depends both on mean growth rate and its duration (*cf.* Fig. 2a). Thus in general terms, phenology is one determinant of overall growth. In comparisons of plant growth over various G x E combinations, the effect of phenology may be very large relative to differences in mean growth rate, so that phenology alone can be used as an efficient predictor of plant response. Thus it was possible to use a single curve analogous to Figure 2a to describe maximum DM production of a wide range of soybean cultivar x sowing date combinations as a function of phenology (Lawn and Byth 1974).

In many cases, however, G x E interactions may differentially affect growth rates, so that such a simple predictive model does not apply. For example, with the Asiatic *Vigna* spp. differential growth rate response to temperature variation across sowing dates was so large that efficient prediction of maximum DM accumulation required both a knowledge of phenology and growth rate (Lawn 1979b). Data from pigeonpea in the same general environment (Akinola and Whiteman 1975) suggest a similar story. Linear regression of maximum DM production on growing degreedays from sowing to pod filling accounted for 72% of the variation in

DM among 32 cultivar x sowing date combinations, compared with only 40% for the regression against days from sowing to pod filling. In these cases, it becomes necessary to consider a family of curves of differing mean growth rate (Fig. 2b).

In many instances the effect of genetic/environmental factors may be sufficiently regular to produce families of curves, e.g. the effect of sowing density on LAI accumulation (Fig. 2c). Like temperature in the earlier example, the effect of density is to alter the mean growth rate; in this case, of LAI. Optimum sowing density, in the absence of other limiting factors, should be that which enables full light interception to be attained immediately prior to pod fill ing, but which avoidsthe accumulation of LAI far in excess of this requirement. It is apparent from Figure 2c that with shorter duration phenologies, higher initial sowing densities are needed to obtain that optimum. Phenology in short-day pulses depends in turn on sowing date and cultivar maturity type, thus providing the basis of the cultivar x sowing date x density interactions in these crops (Carter and Boerma 1979; Lawn et al. 1977; Wallis et al. 1979). Recognition of these interactions has led to the development of systems exploiting short-season growth (Spence and Williams 1972; Wallis et al. 1979).

In this context, some advance comment on the potential contribution of hybrid vigor in pigeonpea is possible. If the basis of hybrid vigor lies in greater vegetative growth, the potential exists for reducing sowing density for cultivars of a given phenology. Alternatively, shorter season cultivars may be used to attain the same canopy development, and this may be an attractive option where the crop is grown on stored water or where double cropping is possible. If the basis of hybrid vigor proves to be increased HI, the options are to maintain density and increase yields, or again, where the crop is grown on stored water, reduce densities and maintain yield potential at the existing level.



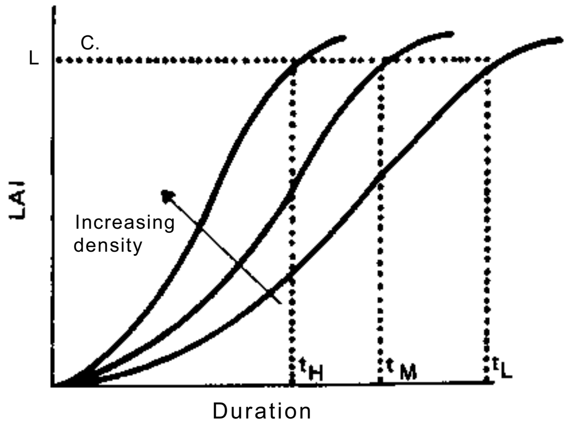


Figure 2. Time course of growth functions (a) standard growth curve, lb) impact of temperature on rate of growth, (c) impact of sowing density on LAI accumulation, tH, fM, *and tL indicate the time from sowing to the attainment of LAI at high, medium and low densities, respectively. Maximum LAI attained at each density will depend on the impact of mutual shading on senescence and on time-dependent factors that may limit growth.*

Specific environmental constraints that are largely unpredictable—such as temporary waterlogging or variable periods of water stress — may be expected to confound a model as simple as that outlined above. For example, in environments where periods of water stress are likely, water rather than radiation may be the main factor limiting canopy productivity. Optimum LAI would then be determined more by considerations of rate of water use, and optimum sowing densities may be lower than in well-watered conditions (e.g. Lawn et al. 1977). Further refinement is therefore necessary to accommodate such contingencies into the prediction process, a prerequisite for which is an adequate understanding of the physiological basis of response to those constraints.

Defining Research Objectives

The cropping strategy ultimately adopted from an exercise of matching a priori crop to environment will depend on the expectations for success of the various agronomic and breeding tasks associated with alternatives available. The potential value of the exercise lies in both the optimization of strategy and the clear definition of agronomic and breeding objectives. In terms of breeding, information is generated on the type of phenology required, the phonological response types most appropriate for use as parental material and the genetic characteristics required to overcome the environmental constraints associated with the strategy ultimately adopted.

The agronomist develops a clearer picture of the phenology type and the environmental constraints around which he must develop optimum agronomic practice.

Clearly, the success of such an exercise is conditional upon:

1. adequate knowledge of the ecophysiological control of ontogenesis in pigeonpea to enable successful prediction of phenology;
2. definition of the range of phenological response types availabe for breeding in pigeonpea;
3. recognition of the major ecological constraints to pigeonpea performance and an adequate understanding of the degree of constraint imposed;
4. definition of differential response types available for respective ecological constraints, and
5. adequate prior knowledge of the likely ecological constraints associated with particular environments.

It is the role of physiologists in collaboration with plant breeders, agronomists, pathologists, entomologists, and meteorologists to provide this basic ecophysiological knowledge. At this stage of pigeonpea improvement the available knowledge is sketchy, and much work remains to be done. As outlined in this paper, however, enough is known to encourage the view that physiological research has potential for substantial contribution to pigeonpea improvement. It remains for that potential to be fulfilled.

Most sensibly, ecophysiological research in pigeonpea will involve complementary roles for controlled environment and field experimentation. Controlled environments enable the selective variation in orthogonal combination of several single environmental factors, so that simple interactions between them can be evaluated. Field experimentation enables both the initial identification of the range of response types available and the observation of plant response to simultaneous variation in a range of environmental factors in a wide range of genotypes. Field experimentation necessarily encounters complex multifactor interactions, the components of which cannot be readily separated. However, the field is the final arbiter of plant response in the real world and can generate much valuable information on the ecophysiology of adaptation.

References

AGGARWAL, V. D., and POEHLMAN, J. M. 1977. Effects of photoperiod and temperature on flowering in mung bean (*Vigna radiata* [L.] Wilczek). Euphytica 26: 207-219.

AKINOLA, J. O., and WHITEMAN, P. C. 1975. Agronomic studies on pigeonpea (*Cajanus cajan* [L.] Millsp.). I. Field responses to sowing time. Australian Journal of Agricultural Research 26: 43-56.

ANGUS, J. F., LISBON, S. P., HSIAO, T. C, and HASEGAWA, 1979. Yield, growth, and root development in relation to water stress and water use for six upland crops and rice. *In* Proceedings, Crop Science Society, Los Banos, Philippines.

BEECH, D. F., LAWN, R. J., and BYTH, D. E. 1979. Irrigated soybean research in northern Australia. *In* Proceedings, INTSOY Conference on Irrigated Soybean in the Tropics. Sep 1979, Cairo, Egypt.

BYTH, D. E., 1968. Comparative photoperiod responses for several soybean varieties of tropical and temperate origin. Australian Journal of Agricultural Research 19: 879-980.

BYTH, D. E., and LAWN, R. J. 1971. The implications of photoperiodic response on soybean breeding procedures and objectives. Australian Plant Breeding Conference working paper 1(b): 14-16.

BYTH, D. E., WALLIS, E. S., and SAXENA, K. B. 1981. Adaptation and breeding strategies for pigeonpea. Session 10, these Proceedings.

CARTER, T. E., and BOERMA, H. R. 1979. Implications of genotype x planting date and row spacing interactions in double cropped soybean genotype development. Crop Science 19: 607-610.

COOPER, R. L. 1977. Response of soybean cultivars to narrow rows and planting rates under weed-free conditions. Agronomy Journal 69: 89-92.

CRISWELL, J. G., and HUME, D. J. 1972. Variation in sensitivity to photoperiod among early maturing soybean strains. Crop Science 12: 657-660.

EMERSON, B. N., and MINOR, H. C. 1979. Response of soybeans to high temperature during germination. Crop Science 19: 553-556.

FISHER, J. E. 1963. The effects of short days on f ruitset as distinct from flower formation in soybeans. Canadian Journal of Botany 41: 871-873.

FRANQUIN, D. 1974.Formulation des phenomenes apparents de photo thermoperiodisme en conditions naturelles. Principes de base. Cahier Orstom Serie Biologie 23: 31-43.

GARNER, W. W., and ALLARD, H. A. 1923. Further studies in photoperiodism, the responses of the plant to relative length of day and night. Journal of Agricultural Research 23: 871-920.

GREEN, D. E., PINNELL, E. L., CAVANAUGH, L. E., and WILLIAMS, L. F. 1965. Effect of planting date and maturity d8te on soybean seed quality. Agronomy Journal 57: 165-168.

GREEN, J. M., SHARMA, D., SAXENA, K. B., REDDY, L. J. and GUPTA, S. C 1979. Pigeonpea breeding at ICRISAT. Presented at the Regional Workshop on Tropical Grain Legumes, University of the West Indies, June 1979, St. Augustine, Trinidad.

HUANG, C-Y., BOYER, J. S., and VANDERHOEF, L. N., 1975. Limitation of acetylene reduction (nitrogen fixation) by photosynthesis in soybean having low water potentials. Plant Physiology 56: 228-232.

HUGHES, G., KEATINGE, J. D. H., and SCOTT, S. P. 1980. Pigeonpea as a dry season crop in Trinidad, West Indies. II. Interception and utilisation of solar radiation. Tropical Agriculture (Trinidad) (In press).

HUME, D. J., and JACKSON, A. K. H. 1980a. Frost tolerance in soybeans. Crop Science, (In press.)

HUME, D. J., and JACKSON, A. K. H. 1980b. Low-temperature tolerance in soybeans: pod formation. Crop Science. (In press.)

ICRISAT annual report 1975-76. India: ICRISAT, Patancheru, A.P. 502 324.

JOHNSON, H. W., BORTHWICK, H. A., and LEFFEL, R. C. 1960. Effects of photoperiod and time of planting on rates of development of the soybean in various stages of the life cycle. Botanical Gazette 122: 77-95.

KEATINGE, J. D. H., and HUGHES, G. 1981. Planting density effects on the dry season productivity of short season pigeonpeas in the West Indies. II. Yield and moisture supply. Volume 2, these Proceedings.

LAWN, R. J. 1979a. Agronomic studies on *Vigna* spp. in south-eastern Queensland. I. Phenological response of cultivars to sowing date. Australian Journal of Agricultural Research 30: 855-870.

LAWN, R. J. 1979b. Agronomic studies on *Vigna* spp. in south-eastern Queensland. II. Vegetative and reproductive response of cultivars to sowing date. Australian Journal of Agricultural Research 30: 871-882.

LAWN, R. J., and BYTH, D. E. 1973. Response of soybeans to planting date in south-eastern Queensland. I. Influence of photoperiod and temperature on phasic development patterns. Australian Journal of Agricultural Research 24: 67-80.

LAWN, R. J., and BYTH, D. E. 1974. Responses of soybean to planting date in south-eastern Queensland. II. Vegetative and reproductive development. Australian Journal of Agricultural Research 25: 723-727.

LAWN, R. J., and BYTH, D. E. 1979. Soybeans. Pages 198-231 *in* Australian field crops II (eds. A. Lazenby and J. Lovett). Sydney, Australia: Angus and Robertson.

LAWN, R. J., BYTH, D. E., and MUNGOMERY, V. E. 1977. Response of soybeans to planting date in south-eastern Queensland. III. Agronomic and physiological response of cultivars to planting date. Australian Journal of Agricultural Research 28: 63-79.

MAJOR, D. J., JOHNSON, D. R., TANNER, J. W., and ANDERSON, I. C. 1975. Effects of daylength and temperature on soybean development. Crop Science 15: 174-179.

MONTEITH, J. L. 1972. Solar radiation and productivity in tropical ecosystems. Journal of Applied Ecology 9: 747-766.

Nix, H. A., MCMAHON, J., and MACKENZIE, D. 1977. Potential areas of production and the future of pigeonpea and other grain legumes in Australia. *In* The potential for pigeonpea in Australia; (eds. E. S. Wallis and P. C. Whiteman). St. Lucia, Brisbane, Australia: University of Queensland.

POLSON, D. R. 1972. Day neutrality in soybeans. Crop Science 12: 773-776.

RAWSON, H. M., and CONSTABLE, G. A. 1981. Gas exchange of pigeonpea: a comparison with other crops and a model of carbon production and its distribution within the plant. Session 5, these Proceedings.

ROBERTSON, G. W. 1968. A biometeorological time scale for a cereal crop involving day and night temperatures and photoperiod. Biometeorology 12: 191-222.

SHAW, R. H., and L AING, D. R. 1966. Moisture stress and plant response. Pages 73-94 *in* Plant environment and efficient water use (eds. W. H. Pierre, D. Kirkham, J. T. Pesek, and R. H. Shaw). Madison, Wis, USA: American Society of Agronomy.

SHELDRAKE, A. R., and NARAYANAN, A. 1979. Growth, development and nutrient uptake in pigeonpeas (*Cajanus cajan*). Journal of Agricultural Science (Cambridge) 92: 513-526.

SHIBLES, R. M., and WEBER, C. R. 1965. Leaf area, solar radiation interception and dry matter production by soybeans. Crop Science 5: 575-577.

SHIBLES, R. M., and WEBER, C. R. 1966. interception of solar radiation and dry matter production by various soybean planting patterns. Crop Science 6: 55-59.

SPENCE, J. A., and WILLIAMS, S. J. A. 1972. Use of photoperiod response to change plant design. Crop Science 12(1): 121-122.

SPRENT, J. I. 1976. Pages 291-351/ *in* Water deficits and plant growth (ed. T. T. Kozlowski). New York: Academic Press.

SUMMERFIELD, R. J. 1977. Vegetative growth, reproductive ontogeny and seed yield of selected tropical grain legumes. *In* Crop protection agents — their biological evaluation. London: Academic Press.

SUMMERFIELD, R. J., and WIEN, H. C. 1980. *In* Advances in legume science (eds. R. J. Summerfield and A. H. Bunting). Kew, England: Royal Botanic Gardens.

SUMMERFIELD, R. J., MINCHIN, F. R., and ROBERTS, E. H. 1978. Realization of yield potential in soybean (*Glycine max* [L.] Merr.) and cowpea *(Vigna unguiculata* [L.] Walp.) Pages 125-134 in Proceedings, BCPC/BPGRG Symposium. British Crop Protection Council and British Plant Growth Regulator Group, 4-5 Jan 1978, Reading, UK.

TANNER, J. W., and HUME, D.J. 1975. The use of growth chambers in soybean research. *In* World soybean research (ed. L. D. Hill), Danville, III, USA: Interstate.

TURK, K. J., HALL, A. E., and ASBELL, C. W. 1980. Drought adaptation in cowpea. I. Agronomy Journal 72: 413-420.

TURNBULL, L. V., WHITEMAN, P. C, and BYTH, D. E. 1981. The influence of temperature and photoperiod on floral development of early flowering pigeonpea. Volume 2, these Proceedings.

VAN SCHAIK, P. H., and PROBST, A. H. 1958. Effects of some environmental factors on flower production and reproductive efficiency in soybeans. Agronomy Journal 50: 192-197.

WALLIS, E. S., WHITEMAN, P. C, and AKINOLA, J. O. 1975. Pigeonpea *(Cajanus cajan* |L.) Millsp.) research in Australia. Pages 149-166 *in* Proceedings, International Workshop on Grain Legumes. ICRISAT, 13-16 Jan 1975, Hyderabad, India.

WALLIS, E. S., WHITEMAN, P. C, and BYTH, D. E. 1979. Pigeonpea *(Cajanus cajan* |L.| Millsp.) production systems in Australia. Presented at the Regional Workshop on Tropical Grain Legumes, University of the West Indies, 18-22 June 1979, St. Augustine, Trinidad.

WALLIS, E. S., BYTH, D. E., and WHITEMAN, P. C. 1980. Mechanized dry seed production of pigeonpea. Session 1, these Proceedings.

Effect of Population Density on Growth Pattern and Yielding Ability in Pigeonpea

D. INI. Singh and A. K. Kush*

Abstract

In a study of growth pattern and yielding ability in response to competitive and noncompetitive spacing, ten cultivars of pigeonpea differing markedly in their canopy structure and other morphological traits were grown in the field during kharif 1978 and 1979. Competitive spacing was obtained by keeping rows 50 cm apart and plants 20 cm apart. In noncompetitive spacing, rows were at 150 cm and plants at 50 cm spacing.

Crop growth decreased in competitive as compared with noncompetitive spacing in all cultivars. Attributes of growth, particularly stem diameter and canopy width, were severely reduced. Spacing affected the partitioning of dry matter into seeds. The mean harvest index (the ratio of grain to biological yield) was relatively high under noncompetitive conditions in all the cultivars, with a few exceptions.

The pod number and filled grain percentage increased in noncompetitive spacing, showing greater amount of light availability.

Considering the leaf canopy development and partitioning of dry matter into grain, it was concluded that a genotype that had a steady rate of growth and moderate harvest index would be desired. In addition, the genotypes should have a moderate value of plasticity index for wide adaptability and consistently high grain yield under limited soil moisture. The impact of a study of this kind on the problems of an intercropping system is briefly discussed.

In India mixed cropping has been the predominant agricultural practice used by the great majority of farmers under rainfed conditions. It involves simultaneous growing of a leguminous crop in association with a cereal or other crops on the same piece of land. In effect, this has offered many advantages to the cultivators (Pathak 1970; Dempster and Coaker 1974; Way 1977; Browning and Frey 1969; Trenbath 1974; Willey 1979).

In northern parts of the country, late-maturing pigeonpea (over 260 days) are generally sown mixed with quick-growing sorghum/millets in the kharif season. Under such a cropping system, the growth of piegonpea is slow during the first 4 months because of various factors such as weather, soil and crop genotypes. Pigeonpea picks up growth and covers space after the accompanying sorghum/millet crop is harvested. Flowering and pod development stages are relatively free from competition for the effective use of soil resources.

With the advent of high-yielding varieties of cereals and millets and of new technology of crop management, the scope for identifying a physiologically efficient genotype in pigeonpea becomes imperative. Since crop compatibility per seconstitutes an essential ingredientforthe success of an improved cropping system, clear understanding of the nature of growth patterns in pigeonpea in such a situation will aid in evolving a suitable type that will withstand the early competition and then be able to utilize available resources efficiently after the harvest of the accompanying sorghum or millet crop.

Physiological approaches directly relevant to the development of pigeonpeas with specific adaptation to a mixed cropping system have recently been emphasized (Laxman Singh, un-

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published). Although such a cropping system has long been practiced in India, there is little detailed information available with emphasis on growth and development of pigeonpea in this country (Mukherjee 1960; Singh et al. 1971; Sheldrake and Narayanan 1979) or anywhere else (Akinola et al. 1975; Akinola and Whiteman 1975). In order to generate information directly useful in development of late-maturing pigeonpea for such cropping systems, field studies were initiated to investigate the genotypic and environmental factors affecting the crop growth pattern and yielding ability. This paper describes certain aspects of growth and yielding ability in ten genotypes grown under two populations.

Materials and Methods

Field experiments were conducted during the seasons of 1978 and 1979 at the Project Directorate (Pulses), IARI Regional Station, Kanpur, U.P., using ten late-maturing pigeonpea cultivars (Gonda local, Azamgarh local, KWR-1, Derapur local, Kanpur local, T-7, AS-29, T-17, Allahabad local, and T-15-15) which differ markedly in canopy structure and physiological characters (Table 1).

The experimental field had a deep alluvial sandy loam of medium texture, with good aeration and moisture-holding capacity. Before sowing, the soil was fertilized with single superphosphate (75 kg P_2O_5/ha) and muriate of potash (25 kg K_2O/ha). Nitrogen was not applied as the crop mostly depended on its own supply obtained by fixing atmospheric nitrogen.

A split-plot design with three replications was used, with plots measuring 7.5 x 7m and divided from each other by a bund of 1 m. Two row widths (1.5 and 0.5 m) for two plant populations (20 000 and 100 000 plants/ha) were used to obtain no competition and maximum competition for light, nutrients, and soil moisture. Seeds were dibbled on ridges at a depth of about 2.5 cm on 11 July each year, soon after the beginning of the monsoon rain. Irrigation was not given and the crops experienced some moisture stress during the winter season, when it is generally dry and crops depend on stored moisture in the soil. To obtain the desired plant populations in rows, three seeds were dibbled and the seedlings were thinned to one at the second trifoliate stage of development. Mechanical weed control measures and endosulfan spray were used at fortnightly intervals to reduce the damage by weeds and insect pests.

The following growth observations were made on ten plants randomly selected from each plot at monthly intervals.

- Plant height.
- Stem diameter at first node.
- Number of nodes on the main stem.

Table 1. Growth habit and maturity of ten pigeonpea cultivars used In population density experiments.

Cultivar	Growth habit[a]	Maturity
Gonda local	Tall, bushy/compact, densely branched at the base with few branches at top. More clusters, open type	Late
Azamgarh local	Tall, open/spreading, densely branched throughout the stem, medium cluster type	Late
KWR-1	Tall, open/spreading, slight divergent branching, medium to low cluster type	Late
Derapur local	Tall, open/spreading, branching at the middle of stem, medium cluster type	Late
Kanpur local	Tall, open, sometimes bushy, highly divergent branching, medium cluster	Late
T-7	Tall open/spreading, divergent branching	Late
AS-29	Tall, bushy, densely branched from the base. More clusters	Late
T-17	Tall, open/spreading, medium branching	Late
Allahabad local	Dwarf, bushy/compact, densely branched at the base, very large size of clusters, compact type	Mid-season to late
T-15-15	Dwarf, open, branching all along the stem, with flowers starting from the base of the stem	Mid-season to late

a. Shape of the plant and size of all parts varied in relation to environment.

- Number of leaves on the main stem.
- Canopy width.
- Number of primary branches on the main stem.
- Date of 50% flowering.

At harvest, the following yield attributes were recorded per plant from a sample of ten random plants from each plot.

- Effective primary branch number.
- Plant height at which effective primary branches start.
- Length of pod bearing portion.
- Number of pods.
- Mortality of seed (percent).
- Total dry matter.
- Grain yield/m^2.

Results and Discussion

Growth Attributes

It is evident from Figures 1 to 6 that high plant population increased interplant competition as exemplified by various growth attributes. The pattern of response in plant height for the ten cultivars was almost similar throughout the growth stages at both the population densities. However, at harvest most of the cultivars differed in height with respect to plant population. Canopy width in all the cultivars was almost alike at the initial stage (1 month after sowing) in both the populations. The differences, however, became apparent at subsequent stages of

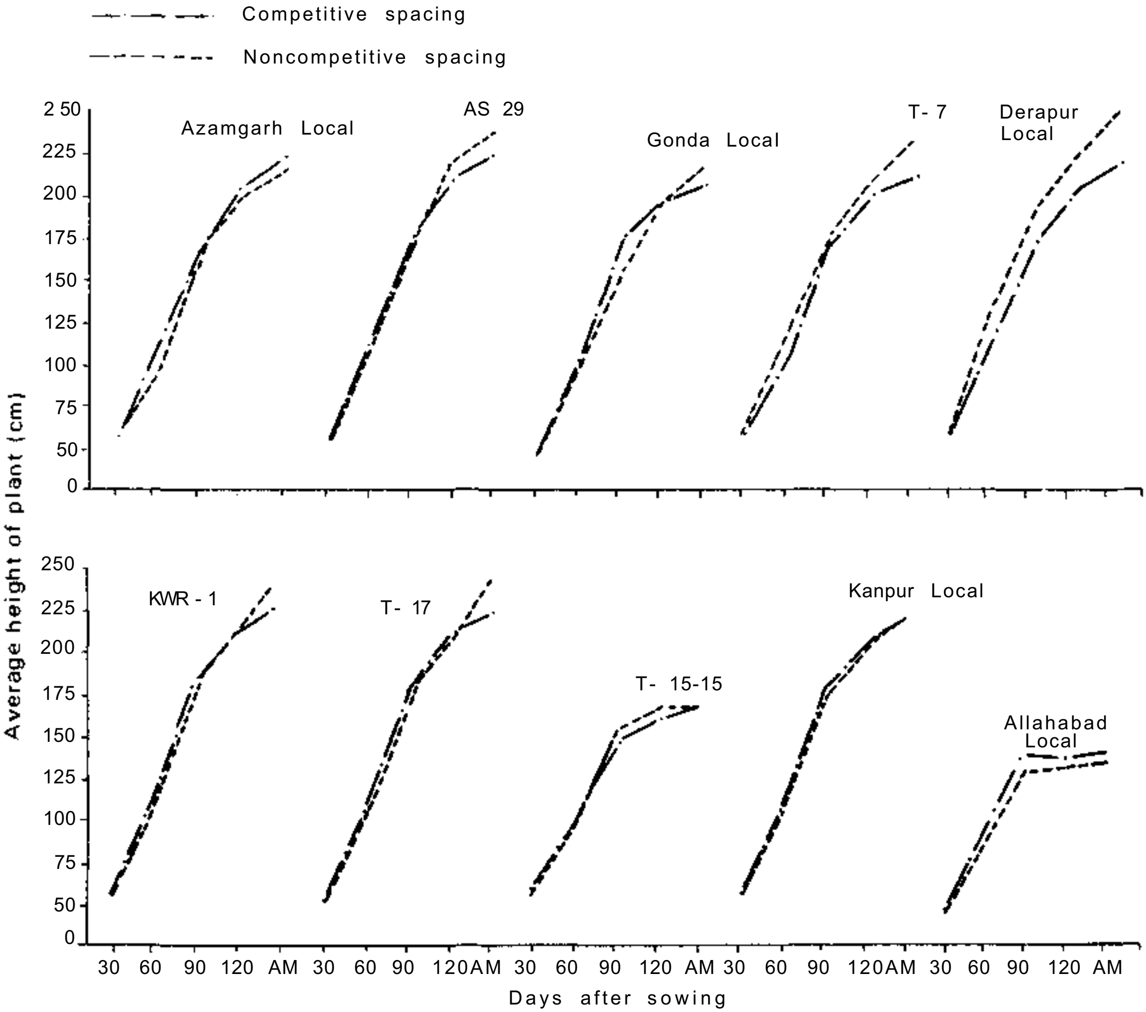

Figure 1, Plant height of pigeonpea cultivars in relation to two population densities.

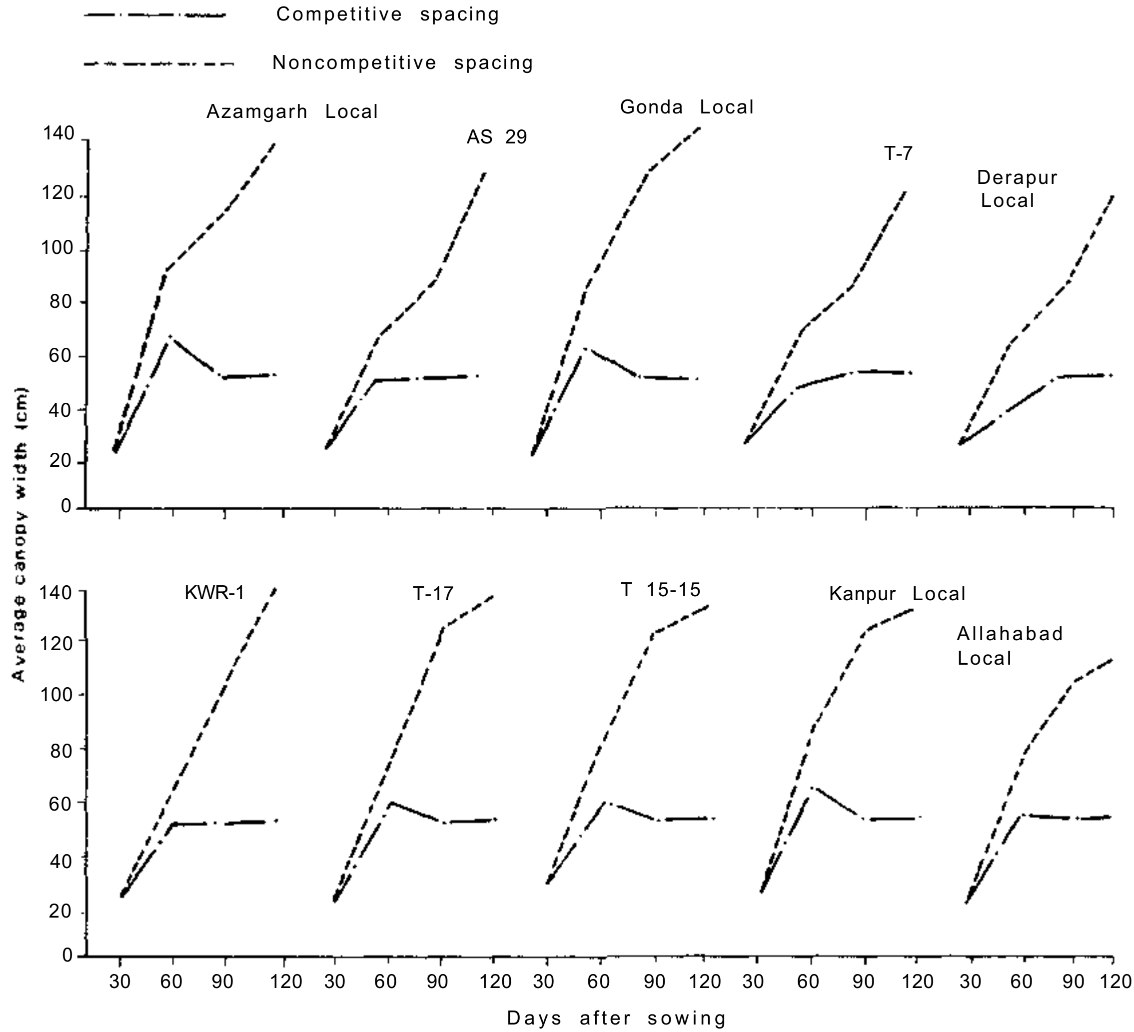

Figure 2. Canopy width of pigeonpea cultivars in relation to two population densities.

growth. Amongst the cultivars, Gonda local had the greatest canopy width, followed by Azamgarh local, KWR-1 and T-17 at noncompetitive spacing (20 000 plants/ha). Cultivar Allahabad local maintained the lowest value until the 4 month stage, followed by Derapur local, T-7, AS-29, T-15-15, and Kanpur local. The better adaptability of Gonda local to noncompetitive spacing may be because its effective primary branches arise from the lower portion of the stem. This enabled the cultivar to cover the land surface more effectively at noncompetitive spacing than the rest of the cultivars. In turn this could assist in intercepting more sunlight at this spacing.

Plant populations had no differential effect on node number and this showed linear increase at subsequent growth stages with the exception of Allahabad local and T-15-15. Average leaf number exhibited a steep rise until 60 days for all the cultivars undertwo populations and then showed differential trends. Cultivars Gonda local and T-17 showed a gradual increase, while Azamgarh local and Kanpur local showed no increase and thus maintained the same leaf number until 120 days. Allahabad local showed an abrupt fall whereas T-15-15 declined gradually. Cultivars AS-29 and KWR-1 started decreasing after recording their highest peak, but at the 120-day stage again showed an increase. No definite trend was noticed in cultivars like Derapur local and T-7.

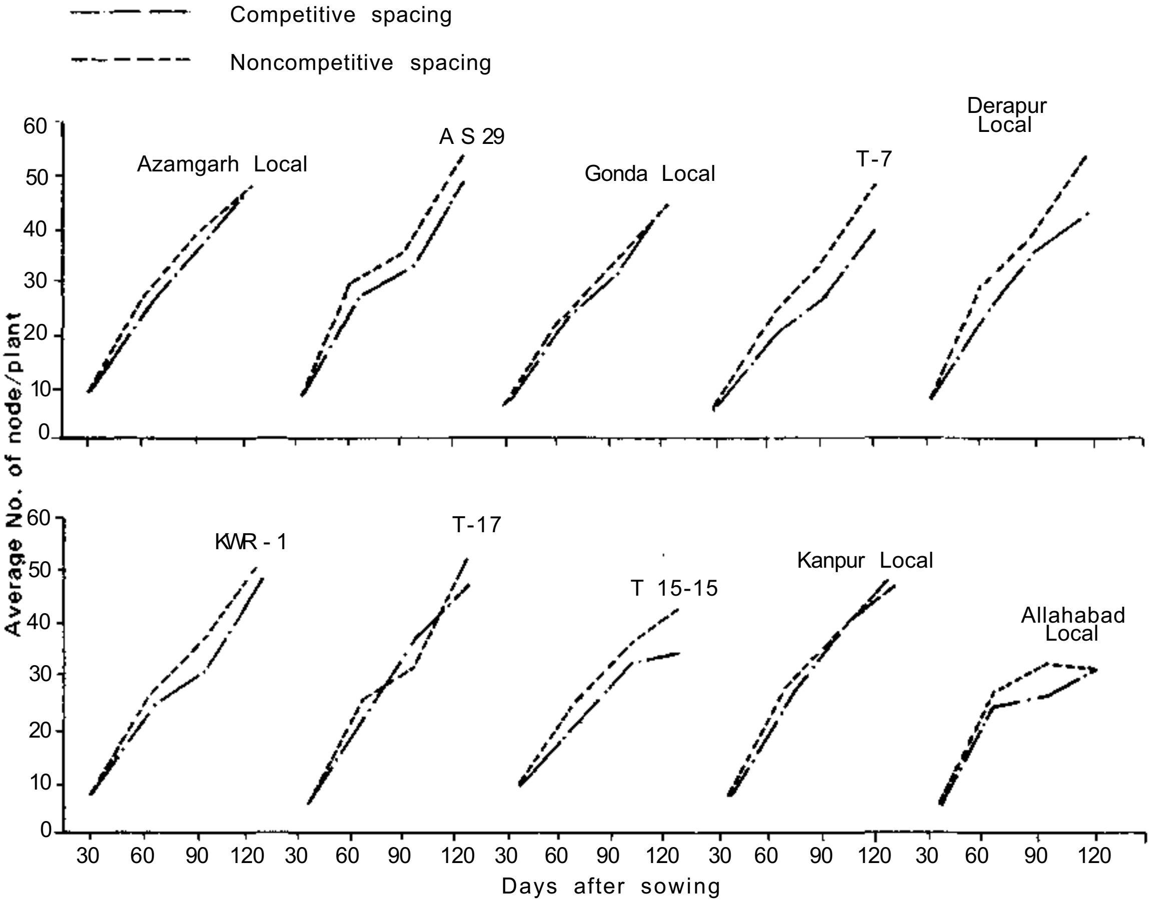

Figure 3. Node number (mother shoot) of pigeonpea cultivars in relation to two population densities.

It seems the process that controlled the leaf number after 60 days operated at a differential level. The lower leaves started dying at a faster rate after attaining the maximum number in cultivars Allahabad local and T-15-15. At later stages, mutual shading under high population proved detrimental in these cultivars. On the other hand, cultivars Gonda local, T-7, T-17, and Kanpur local had the ability to tolerate the adverse effect of mutual shading. From this trend it is apparent that genotypes differed in exploiting their environments at various stages of growth especially if distribution of solar energy throughout the foliage depth is considered.

The response of primary branch number to population density was linear for most of the cultivars, excepting T-15-15. Cultivars Gonda local and Kanpur local behaved almostsimilarly when subjected to two population densities. On the other hand, cvs Derapur local, AS-29, KWR-1, T-17 and T-15-15 were sufficiently sensitive to increased populations. These cultivars tended to have a higher number of primary branches at lower densities than at higher ones. Probably the decreased transmission of solar energy at later stages of crop growth restricted the vegetative development of these genotypes at higher densities.

Stem diameter increased sharply with the low plant population until the 90-day stage, whereas it showed a linear response to increased plant population. In general, the stem diameter was about half the value of what it was under high plant population. This could be explained in part by the fact that photosynthate supply to stem was reduced under high plant population.

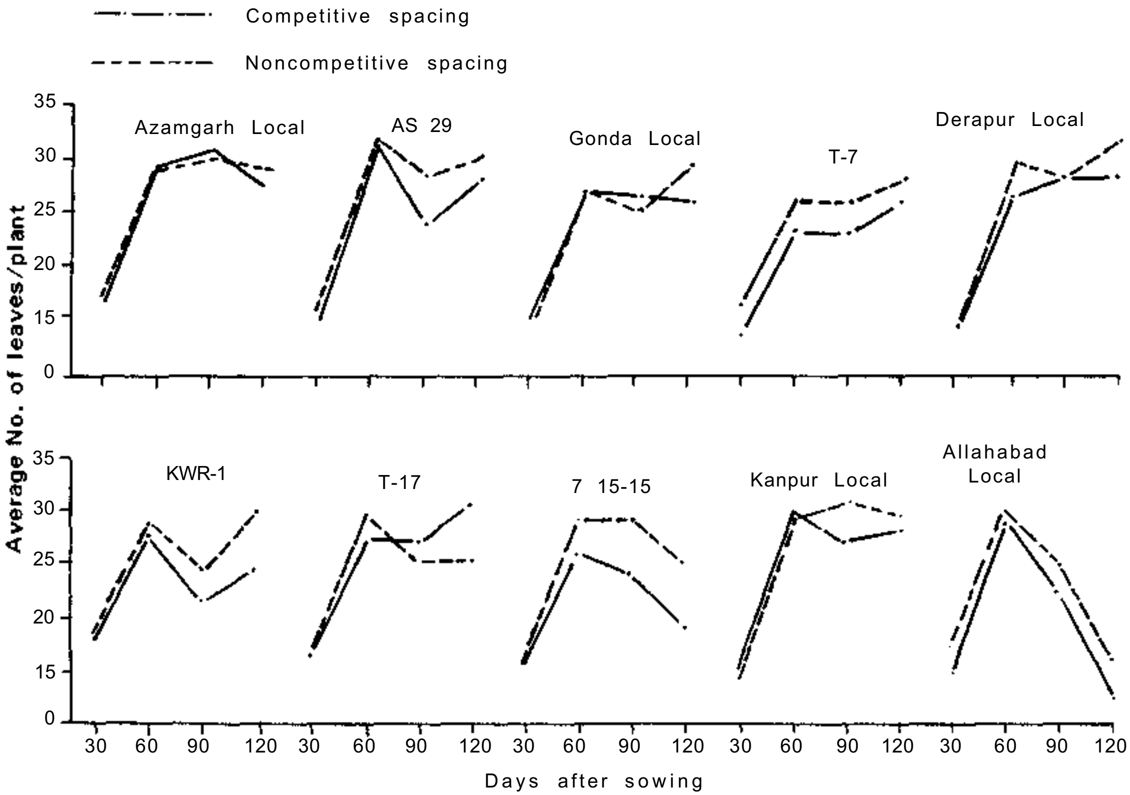

Figure 4. Leaf number (mother shoot) of pigeonpea in relation to two population densities.

Yielding Ability

Dry Matter Yield

The response of dry matter yield per hectare to plant populations differed with the cultivars. It ranged between 15 tonnes/ha and 37.5 tonnes/ha at the highest density of 100 000 plants/ha. At the lowest density of 20 000 plants/ha it ranged between 15 and 40 tonnes/ha. Of these cultivars, T-17 and Kanpur local yielded the highest at noncompetitive spacing (20 000 plants/ha) whereas Derapur local and T-15-15 produced the lowest at competitive spacing (100 000 plants/ha). KWR-1 produced the same amount of dry matter, irrespective of population density. T-7, Azamgarh local, and Allahabad local had increased dry-matter production with competitive spacing as compared with Gonda local, Derapur local, T-17, AS-29, and Kanpur local, which had the highest with noncompetitive spacing.

For wide adaptability of a cultivar, a high plasticity index (PI) must be achieved. A high plasticity index is reflected in the high ratio of the weight of the grain at low population to that at high population. The plasticity of cultivars differed markedly in response to changes in plant population (Table 2). The plasticity index was smallest for Azamgarh local and Allahabad local, largest for Derapur local and T-17, indicating the wide adaptability of the latter two cultivars. Cultivars Gonda local, T-7, and Kanpur local had moderate plasticity index as compared with T-15-15, KWR-1, and AS-29. Since a large plasticity index insured that a cultivar is adapted to a wide range of environments, a moderate value is one of the requisites for consistent high yield under diverse cropping systems.

Harvest index ranged from 7.85 to 23.50 at high plant population and 9.00 to 22.66 at low plant population. Of the ten cultivars, T-7 showed the highest response to noncompetitive spacing, followed by Derapur local. Cultivars KWR-1, Gonda local, and AS-29 exhibited almost equal response to change in plant populations. Harvest index was almost the same in Kanpur local and Azamgarh local under the two

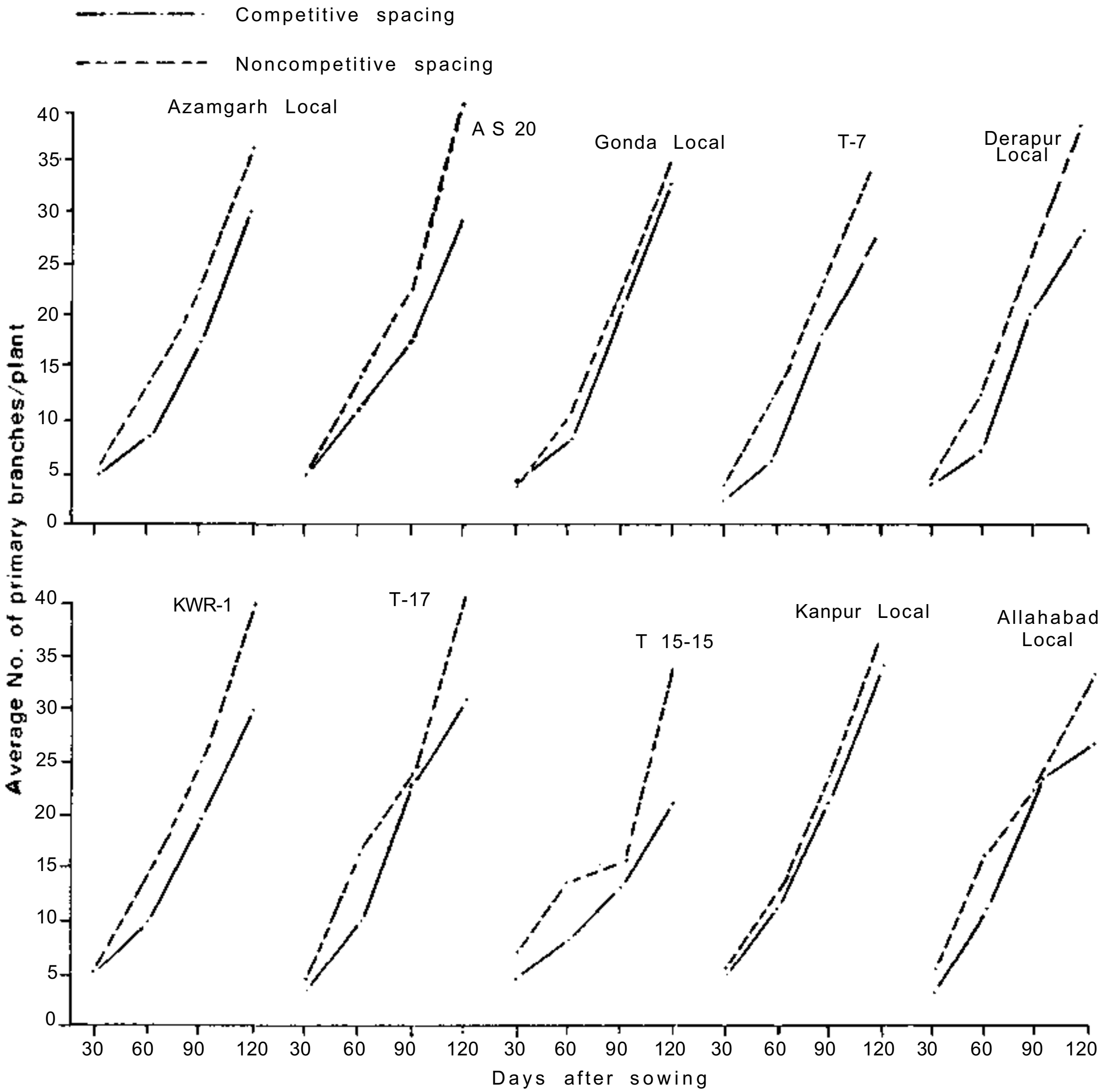

Figure 5. Primary branch number (mother shoot) in relation to two population densities of pigeonpea cultivars.

plant populations. However, cultivar Allahabad local gave negative responseto noncompetitive spacing (20 000 plants/ha). For high and stable grain production, a balanced partitioning of dry matter into grain must be achieved and is reflected in the high ratio of grain to total dry matter produced (harvest index, HI). The factors controlling HI are environment, cultural practices and cultivars.

Grain Yield

Grain yield of all the ten cultivars ranged from 1375 to 4700 kg/ha at competitive spacing (100 000 plants/ha) and 1575 to 6150 kg/ha at noncompetitive spacing (20 000 plants/ha). Cultivars Allahabad local and Azamgarh local yielded highest at competitive, not at noncompetitive, spacing, showing a negative response to increase in spacing. At noncompetitive spacing, Derapur local, Gonda local, Kanpur local, and AS-29 recorded the highest yield. However, the magnitude of response varied again with cultivar types and ranged from 2.00 (for T-15-15) to 41.85 (for Derapur local). Intermediate response obtained in T-17, Gonda local and

Table 2. Effect of population density on varlousattrlbutes of grain yield in tan cultlvars of pigeonpea at harvest.

Cuttivar/ Population density[a]	Grain yield/m^2 (g)	Total dry matter yield/m^2 (g)	Effective primary branch no. (EPB)	Height at which EPB start (cm)	Length of pod bearing portion of stem (cm)	Pod number/ plant	Mortality of seed (%)	Harvest index (HI)	Plasticity index (PI)	Days to 50% flowering
Azamgarh local										
P_2	451.6	3750.0	14.5	57.5	63.3	339.0	36.00	12.04	0.68	110.0
P_1	310.0	2500.0	21.7	23.9	105.6	1179.1	27.00	12.40		113.3
Mean	380 8	3125.0	18.1	40.7	84.45	759.05				
AS-29										
P_2	401.6	2660.0	16.4	86.9	73.6	232.5	47.63	15.09	1.28	123.6
P_1	517.5	3000.0	27.2	25.9	116.0	1132.6	29.64	17.25		126.3
Mean	459.55	2830.0	21.8	56.4	94.30	682.55				
Gonda local										
P_2	342.5	2250.0	14.1	44.9	84.3	254.5	22.00	15.22	1.67	107.0
P.	575.0	3160.0	20.8	20.3	114.3	1252.2	20.00	18.19		109.6
Mean	458.75	27050	17.45	32.6	99.3	753.35				
T-7										
P_2	325.0	3500.0	13.9	86.0	50.3	211.4	49.24	9.28	1.57	111.3
P_1	513.3	2660.0	23.4	23.8	113.6	1096.3	35.68	19.29		123.0
Mean	419.15	3080.0	18.65	54.9	81.95	653.85				
Derapur local										
P_2	197.5	1500.0	15.0	78.5	64.6	201.0	33.06	13.16	3.11	130.0
P_1	615.0	3250.0	31.0	27.6	123.0	1308.1	22.97	18.92		130.0
Mean	406.25	2375.0	33.0	53.0	93.8	154.55				
KWR-1										
P_2	315.0	2250.0	14.3	94.0	58.3	275.8	38.39	14.00	1.15	119.0
P_1	365.0	2250.0	25.3	22.0	115.0	890.5	36.57	16.22		127.3
Mean	340.0	2250.0	19.8	58.0	86.65	583.15				
T-17										
P_2	230.0	2750.0	14.4	87.5	68.3	162.3	31.28	8.36	2.09	113.66
P_1	482.6	4000.0	26.6	25.7	112.6	1359.7	26.25	12.06		113.0
Mean	356.25	3375.0	20.5	56.6	90.45	761.0				
T 15-15										
P_2	137.5	1750.0	10.3	28.4	69.3	57.9	76.46	7.85	1.14	86.0
P_1	157.5	1750.0	17.4	22.0	104.6	367.3	61.72	9.00		85.0
Mean	427.25	3250.0	18.8	25.2	88.95	847.65				
Kanpur local										
P_2	327.5	2500.0	15.2	51.7	69.6	286.6	21.30	13.10	1.30	110.0
P_1	527.0	4000.0	22.4	21.3	108.3	1408.7	18.72	13.17		113.3
Mean	421.25	3250.0	18.8	36.5	88.95	847.65				
Allahabad local										
P_2	470.0	2000.0	15.2	30.7	39.6	412.4	24.02	23.50	0.72	87.0
P_1	340.0	1500.0	25.0	16.1	78.0	928.5	24.94	22.66		87.3
Mean	405.0	1750.0	20.1	23.4	58.8	670.45				
Mean P2	319.82	2491.0	14.33	64.6	64.02	243.26				
Mean P_1	440.28	2807.0	24.08	20.9	109.10	1093.30				

Continued

Table 2. *Continued.*

Cultivar/ Population density	Grain yield/m^2 (g)	Total dry matter yield/m^2 (g)	Effective primary branch no.(EPB)	Height at which EPB start (cm)	Length of pod bearing portion of stem (cm)	Pod number/ plant	Mortality of seed (%)	Harvest index (HI)	Plasticity index (PI)	Days to 50% flowering
LSD (5%)										
Variety	40.5757	0.3706	3.5328	14.35	38.7117	486.3289	NSA[b]	NSA[b]	NSA[b]	NSA
Spacing	11.9050	0.1020	2.7466	9.49	8.1963	58.0858				
Variety x spacing	37.6481	0.3295	8.6861	30.03	25.9198	269.0660				

a P_2 = Population density 100 000 plants/ha; P_1 = 120 000 planta/ha.
b. NSA = Not statistically analyzed.

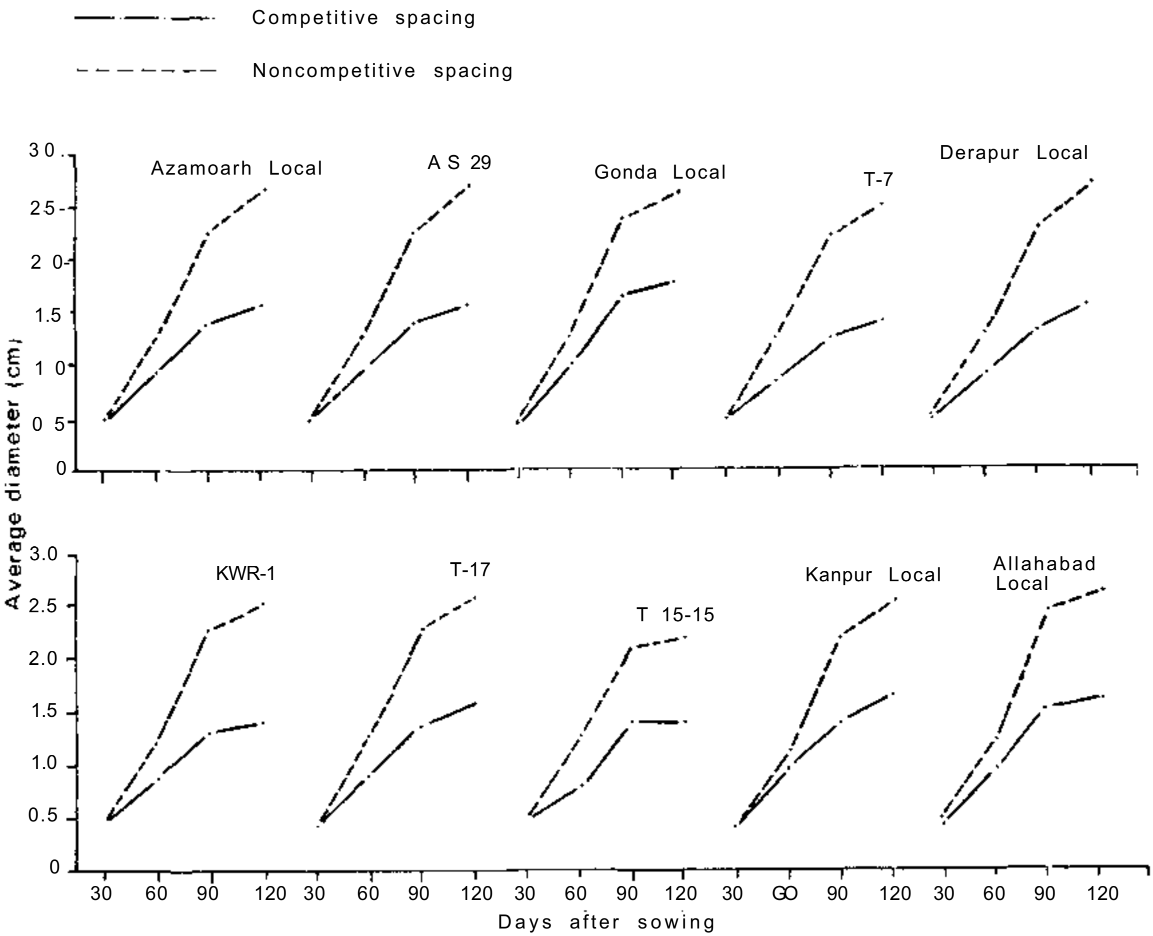

Figure 6. Stem diameter of pigeonpea cultivars in relation to two population densities.

Kanpur local indicated that these cultivars are fairly stable in grain production over the others, because they could adjust to cultural manipulation and probably tolerate the shading effect arising from high plant population. On the other hand, cv Derapur local, though recording highest yield at noncompetitive spacing, suffered heavily at competitive spacing. In turn, this clearly exhibited the inability of Derapur local to tolerate the adverse effect of shading obtained at high plant population. These results suggest that pigeonpea breeders should look for lines that have relatively intermediate response for canopy structure, PI, and HI to population pressure, particularly in mixed cropping systems.

Factors Controlling Yielding Ability at High Plant Population

Grain yield was severely reduced at high plant population because of the combined influence of decreased number of primary branches, reduced pod number, filled grain percent, and pod-bearing stem length. The length of the reproductive zone was drastically reduced at high plant population and thus indicated the close relationship of the development of yield attributes and plant population. These observations confirmed earlier work (Hammerton 1971; Singh et al. 1971). These results thus suggest that cultivars differ in their response to plant density. Cultivars with steady growth at the initial stage along with the ability to cover the land surface effectively after the removal of the companion crop should be selected. In addition, they should be able to withstand the adverse effect of shading at the initial stage, and make an optimum compromise between dry matter production and its conversion to grain. However, further experimentation is needed to record data on light distribution patterns through the canopy profile, rooting pattern, incidence of major pests and diseases, and biological nitrogen-fixation capacity of the cultivar at various growth stages under varying cultural conditions and cropping systems.

References

AKINOLA, J. O., and WHITEMAN, P. C. 1975. Agronomic studies on pigeonpea (*Cajanus cajan* [L.] Millsp.) 2. Responses to sowing density. Australian Journal of Agricultural Science 26 (1): 57.

AKINOLA, J. 0., WHITEMAN, P. C, and WALLIS, E. S. 1975. The agronomy of pigeonpea. CAB Review series 1/1975. Hurley: Commonwealth Bureau of Pasture and Field Crops.

BROWNING, J. A., and FREY, K. J. 1969. Multiple crop as a means of disease control. Annual Review of Phytopathology 7: 355.

DEMPSTER, J. P., and COAKER, T. K. 1974. Diversification of crop systems as a means of controlling pests. *In* Biology in pest and disease control. Oxford: Blackwell.

HAMMERTON, J. L. 1971. A spacing planting date trial with *Cajanus cajan* (L.) Millsp. Tropical Agriculture (Trinidad) 48: 341.

MUKHERJEE, D. 1960. Studies on spacing of *Cajanus cajan* (L.) Millsp. Indian Journal of Agricultural Science. 30: 177.

PATHAK, G. N. 1970. Red gram. *In* Pulse crops of India ed. P. Kachroo. New Delhi, India: Indian Council of Agricultural Research.

SHELDRAKE, A. R., and NARAYANAN, A. 1979. Growth, development and nutrient uptake in pigeonpeas (*Cajanus cajan).* Journal of Agricultural Science (Cambridge). 92: 513.

SINGH, L., MAHESHWARI, S. K., and SHARMA, D. 1971. Effect of date of planting and plant population on growth, yield and yield components and protein content of pigeonpea (*Cajanus cajan* [L.] Millsp.) Indian Journal of Agricultural Sciences. 41: 353.

TRENBATH, B. R. 1974. Biomass productivity of mixtures. Advances in Agronomy 26: 177.

WAY, M. J. 1977. Pest and disease status in mixed stands versus monocultures. Page 127 *in* The relevance of ecosystem stability. Oxford: Blackwell.

WILLEY, R. W. 1979. Intercropping: its importance and research needs. 1. Competition and yield advantages. Field Crop Abstracts 32(1): 1-10. 2. Agronomy and research approaches. Field Crop Abstracts 32(2): 73-85.

Gas Exchange of Pigeonpea: a Comparison with Other Crops and a Model of Carbon Production and its Distribution Within the Plant

H. M. Rawson and G. A. Constable*

Abstract

This paper compares the gas exchange and carbon distribution patterns of pigeonpea with other dicotyledonous crops. It shows that rates of photosynthesis and transpiration in pigeonpea are relatively low, and that light-saturation of photosynthesis occurs at only one-third full sunlight in young leaves and at less than one-fourth full sunlight in old leaves, but that the rate of decline in gas exchange with leaf aging is similar to that of other crops such as peanuts, cowpea, soybean, sunflower, cotton, and tobacco. No significant differences in gas exchange patterns were discerned between the two pigeonpea varieties examined.

Photosynthesis declined with increasing water stress at a rate similar to that in soybean, sorghum, and sunflower, but because photosynthesis rates in the absence of stress were low, photosynthesis became zero at relatively high leaf water potentials of about -20 bars (-2.0 MPa). This compares with values of approximately -35 bars for sorghum grown under similar conditions. Diurnal patterns of gas exchange are described and explained and the changes in water-use efficiency with increasing stress are discussed,

A computer model that generates dry matter and yield from the single-leaf gas exchange patterns is developed. This demonstrates that under realistic field conditions, carbon availability within the whole plant at flowering is considerably in excess of that required for pod setting. The model indicates that carbon actually available for pod setting is only that produced in the locality of the pod. An hypothesis is proposed which explains the heavy flower drop, poor pod set and yield stability of pigeonpea in terms of high respiration rates of flowers and high resistances in the vascular system of the flower pedicels.

There appear to be no readily available data on the gas exchange of pigeonpea; however, observations on the growth of the crop encourage speculation. The description by Pathak (1970) of pigeonpea as "a plant which thrives in strong sunlight" and which also "thrives under a rainfall of 25 to 37 cm" suggests a crop with gas exchange characteristics similar to those of sunflower. Sunflower, for example, increases its rate of carbon fixation up to very high light levels and has the capacity to extract water from deeper in the soil profile than many other crops (Rawson and Constable 1980), thus ensuring growth when other crops would fail. In support of this picture of pigeonpea as a vigorous plant are the reported growth rates for the crop of up to 17 $gm^{-2}d^{-1}$ (Sheldrake and Narayanan 1979), although itwould seemthatratesof 6to 13 gm^{-2} are closer to the norm.

The low yields of pigeonpea suggest a different image forthe crop. Thefact that potentially fertile flowers do not bear pods unless others are removed (Sheldrake et al. 1979) implies that the crop may be underproducing carbon at this

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time. Yet, on the contrary, a large proportion of the plant's leaves may be removed during the reproductive phase without affecting yields. Whether this means that the majority of the carbon generated by leaves is unavailable for pod growth or that leaves operate well below potential until the sink: source ratio is altered is not at all clear.

It seems that observations of growth patterns in pigeonpea only produce a confused, contradictory picture of its gas exchange. What we attempt to do in this paper is clarify this picture by presenting data on the photosynthesis and transpiration of two varieties of pigeonpea grown either with adequate water or subjected to stress. The gas exchange patterns described are compared with those of other species grown in similar conditions and measured in the same gas analysis system; the peanut data are from plants grown simultaneously with the pigeonpeas. The patterns established for single leaves are combined into a carbon-driven model for a whole crop and this is used to understand the apparently heterodoxical behavior of pigeonpea.

Methods

Inoculated plants of UQ-50 and UQ-68 pigeonpeas and of Virginia bunch peanuts were grown in bins containing 50 kg or 20 kg of potting mix in a glasshouse maintained at a 28°C day and 20°C night temperature. The thermoperiod was 12 hours. There were 50 plants of pigeonpea and 15 of peanut and initially all were provided with adequate water and nutrients. When pigeonpea plants had produced approximately 20 nodes on the main shoot, at 45 days from sowing, water was withheld from 30 plants until they were severely wilted. This took from $1^1/_2$ to 3 weeks. After rewatering and recovery the treatment was repeated.

Photosynthesis and transpiration measurements were made using the open infrared gas exchange system and calculations described in Constable and Rawson (1980a). The single-leaf chambers of the system were used in the glasshouse where the plants were growing. They were provided with supplementary light of 1600 to 1800 $\mu Em^{-2}s^{-2}$ photosynthetically active radiation (PAR). Chamber temperatures varied between 28° and 30°C over the period of the study.

To establish the changes in gaseous fluxes with leaf aging, terminal leaflets were measured several times over a 5-week period. Mainstem leaves from nodes 10 to 35 were included in this analysis (forpeanuts, leaves 3to 10 were measured). Each leaflet nominally commenced expansion (day 0) when it unfolded, that is, when the margins of the leaflet separated. It was found that expansion prior to day 0 was very slow. Leaves abscised between 60 and 90 days later. Leaflet areas were estimated from length by breadth measurements (x 0.707cm^2).

Results and Discussion

This paper is subdivided into three main sections. The first presents data on instantaneous gas exchange patterns of leaves. The second expands these to a diurnal time scale and examines the consequences of changing light, temperature, and humidity regimes. The final section describes a computer model that assembles the patterns into the time scale of the crop.

Instantaneous Measurements

Aging of Leaves and Gas Exchange in Several Species

The common approach to comparing and ranking rates of photosynthesis of cultivars or species is to assess the group from measurements of "young, fully expanded leaves" (e.g., El Sharkawy et al. 1965 for cotton; Lloyd and Canvin 1977 for sunflower; Bhagsari and Brown 1976 for peanut). Unfortunately, there are traps for the unwary that may make such rankings meaningless in terms of dry-matter production.

1. Photosynthesis rates may change very rapidly with leaf age, and unless leaf age is carefully documented, accurate comparisons between groups cannot be made: "Young fully expanded leaves" can cover quite a range of ages.
2. Peak photosynthesis does not necessarily occur immediately leaves reach their final size, it may occur when leaves are only half grown, as in tobacco (Rawson and Woodward 1976). In addition, final size is an elusive value under stress conditions.

3. Rankings of photosynthesis for young leaves can be very different from rankings of 4-week-old leaves when comparisons of wide-ranging materials are made (e.g., Lush and Rawson 1979 for cowpea).
4. Dry-matter production is dependent upon photosynthesis rate *and* area per leaf and the two may be inversely related (Evans and Dunstone 1970 with wheat). Thus any attempts to correlate photosynthesis rate with dry-matter production should account for photosynthesis x area x time.

Bearing in mind these pitfalls, we compare in Figure 1 the patterns of photosynthesis of aging leaves in several species. Only cultivated varieties of each species are considered; while growing conditions varied marginally for the species, all were measured in the same gas analysis system.

It is apparent that species do have different rates, that peanut ranks high, while pigeonpea fixes CO2 slowly. High peak rates also relate to long photosynthesis durations. However, as peak rates are maintained for very few days, a time interval of 10 days could mean a 20% error in the estimation of peak photosynthesis, which is as large a difference as may oocur among a collection of cultivars. What is surprising is that the rate of decline in photosynthesis rate with leaf age is similar across species, ranging from 2 to 2.5 ng CO_2 $cm^{-2}S^{-1}$ reduction per day of aging. It is stressed thatthe examples in Figure 1 are of cultivated varieties. Studies with cowpea have shown that wild lines can have high peak rates of photosynthesis but short durations, a possible reflection of their small carbon requirements for seed-filling (Lush and Rawson 1979). One clear conclusion from Figure 1 is that legumes as a group do not differ from other C3 dicotyledonous crops in their photosynthesis characteristics.

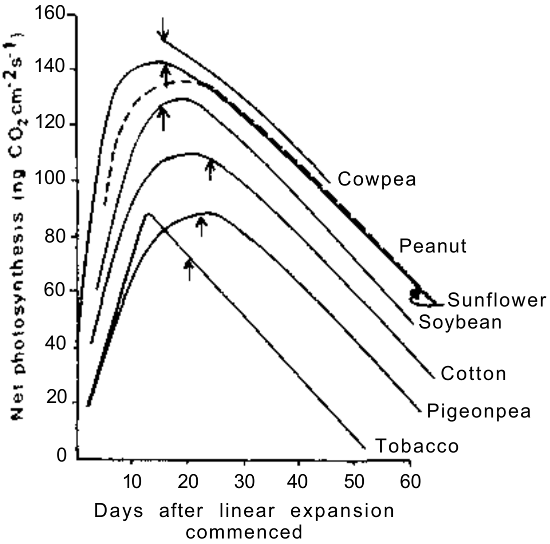

Figure 1. Changes in net photosynthesis of leaves as they age. All measurements made at between 1600 wtl 1800 μ E $m^{-2}s^{-1}$ photosynthetically active radiation (PAR). In all cases except soybean, several leaf positions were used to produce the curves. The timing of the attainment of final area per leaf is shown by arrows. In most cases, the time scale begins when the leaf unfolded but in sunflower and tobacco it commences when the leaf reached 5 cm^2. Data are taken from the following:

Tobacco : Rawson and Hackett 1974; Rawson and Woodward 1976.
Pigeonpea : (Fig. 2, this paper)
Cotton : Constable and Rawson 1980a.
Soybean : Woodward and Rawson 1976.
Sunflower : Rawson and Constable 1980.
Peanut : This paper.
Cowpea : Lush and Rawson 1979. Elite cvs only.

Aging of Pigeonpea Leaves

To demonstrate the variability of gas exchange within a population of plants, the data from which the pigeonpea curve of Figure 1 was derived are shown in Figure 2a. All data are normalized for leaf age, but nevertheless there is something approaching a 30% scatter across the 25 leaf positions measured on up to 50 plants, with the consequence that the slightly higher rates of UQ-50 were not significantly greater than those of UQ-68. This variability underscores the conclusion that many plants need to be measured before a reliable estimate can be made of photosynthesis rate of a variety or species.

As for photosynthesis, rates of transpiration, normalized to constant Vapor Pressure Difference (VPD) were tied to leaf age (Fig. 2b) such

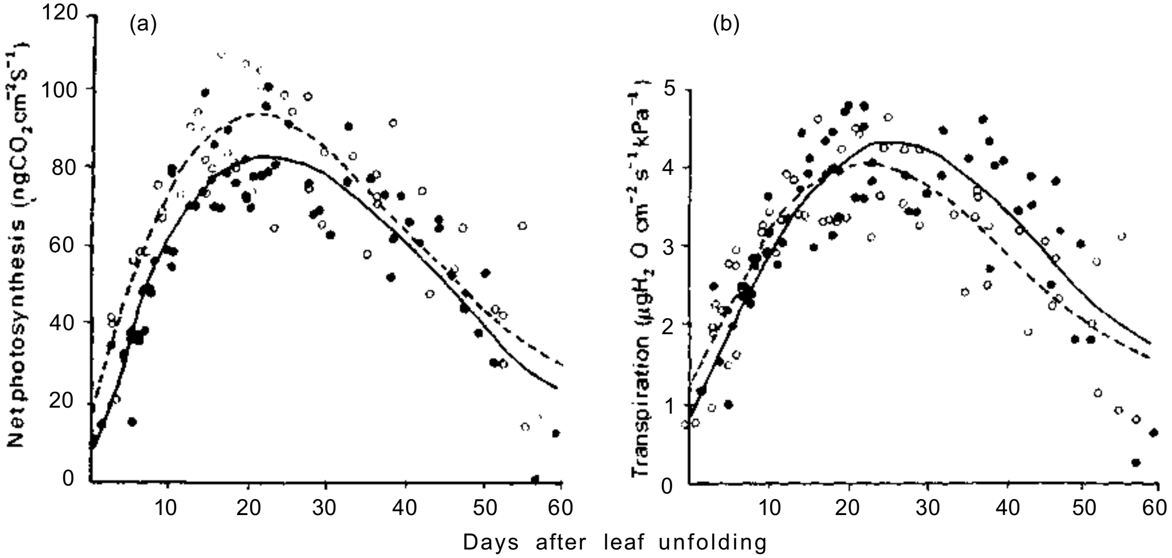

Figure 2. Changes in (a) net photosynthesis and (b) transpiration {expressed per kPa VPD) with leaf aging for pigeonpea cultivars UQ-68 (•) and UQ-50 (o) (——). Each value is an individual measurement, thus demonstrating the spread of response. All measurements were made at between 1600 and 1800 μ E $m^{-2}s^{-1}$ (PAR) light. The fitted curves are for photosynthesis:

$$\text{UQ-68}\quad Y = 0.45 + 7.20Xe^{-.0062X^{1.5}} \qquad r^2 = 0.79$$

$$\text{UQ-50}\quad Y = 11.16 + 7.75Xe^{-.007X^{1.5}} \qquad r^2 = 0.81$$

and for transpiration:

$$\text{UQ-68}\quad Y = 0.80 + 0.226Xe^{-.00075X^2} \qquad r^2 = 0.67$$

$$\text{UQ-50}\quad Y = 1.22 + 0.207Xe^{-.00098X^2} \qquad r^2 = 0.72$$

that expanding leaves had low rates of water loss per unit leaf area, while young, fully expanded leaves transpired relatively rapidly. The more rapid rates of UQ-68 were not significantly different from those of UQ-50. A comparison of Figures 2a and 2b indicates that leaves that were 30 to 50 days old had rapidly declining rates of photosynthesis but not of transpiration, implying that their efficiency of water use was becoming poorer.

Changes in Gaseous Fluxes with Light

The measurements of Figures 1 and 2 were made at irradiance close to that of full sunlight. As a leaf ages and more leaves are produced above it, it will be exposed to progressively decreasing average daily light levels. Consequently, to understand the photosynthesis-versus-age responses for leaves in a canopy, we need to superimpose on Figure 2 the responses of leaves to light. To illustrate the range of response, two leaf ages, 20 days and 50 days from unfolding, are presented in Figure 3. Peak photosynthesis occurred at lower light levels as the leaf aged; at around 800 $\mu Em^{-2}/S^{-1}$ in young leaves and 400 $\mu E\ m^{-2}S^{-1}$ in old leaves. However, in keeping with other species (Ehleringer and Bjorkman 1977), pigeonpea leaves of all ages had a similar efficiency of carbonfixation of 0.27 ngC02 cm^{-2} $(\mu\ E\ m^{-2})^{-1}$ at very low light levels. Thus quantum yield did not change with age in agreement with Horie and Udagawa (1971) for sunflower.

Not only was carbon dioxide fixed more slowly at low light levels, but transpiration rates were also reduced. During the dark hours though, pigeonpea leaves were losing 0.25

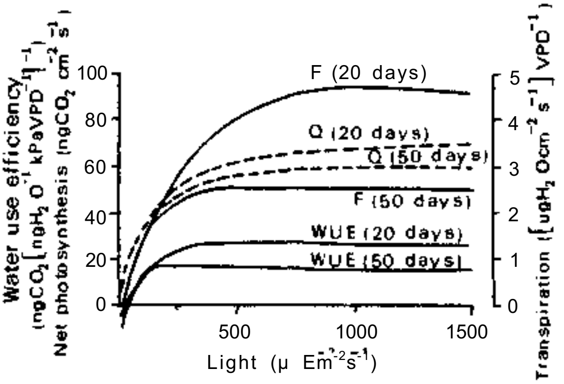

Figure 3. Response of photosynthesis (F), Transpiration (Q) and water use efficiency (W) to light with leaf aging in pigeonpea.

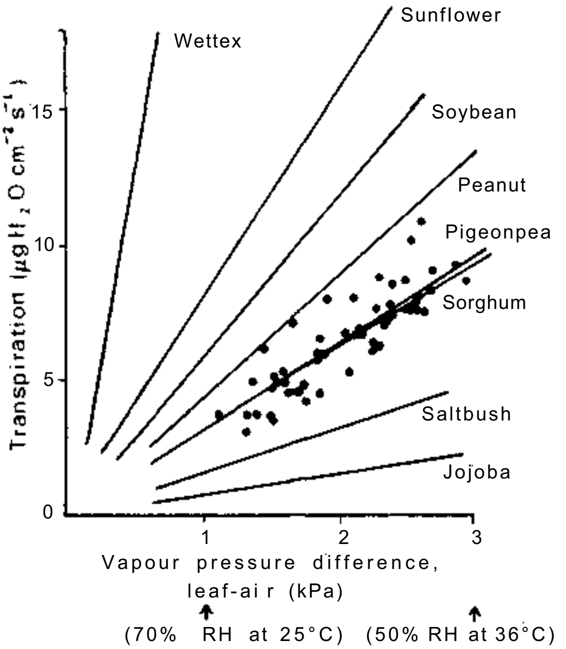

Figure 4. Changes in transpiration with vapor pressure difference between the leaf and air (VPD) for several species of plants and for a freely evaporating surface (Wettex). The data points are for different leaves of pigeonpea to demonstrate the spread of response. Data for jojoba, saltbush, sorghum, and soybean are from Rawson, Begg, and Woodward (1977), for sunflower are from Rawson and Constable (1980) and for peanut and pigeonpea are from this paper.

$\mu gH_2O\ cm^{-2}s^{-1}kPaVPD^{-1}$, equivalent to more than 5g of water per 100 cm^2 of leaf for a night with 80% relative humidity. Only slightly less water was transpired by old leaves than by young leaves; consequently, water-use efficiency (photosynthesis/transpiration VPD^{1}) declined with leaf age.

Changes in Gaseous Fluxes with Humidity

Leaves are exposed to a wide range of humidity over their lives and, as several papers have shown, this may affect their carbon production and the quantity of water transpired per unit of carbon fixed. In the simplest situation of a well-watered plant, as humidity falls and VPD increases, the leaf increases its rate of transpiration, provided there is no stomatal closure and the plant can supply the leaf with water quickly enough to satisfy the evaporative demand. Figure 4 shows this situation and the linear relationship between transpiration and VPD appropriate for several species. Pigeonpea leaves transpired at a rate similar to sorghum leaves but lower than sunflower, soybean, and peanut. The data points demonstrate that there was a broad scatter of response resulting from differences in leaf age and plant-to-plant variation. The range of VPD in Figure 4 of 1 to 3 kPa is similar to the evaporative conditions to which pigeonpea leaves would be exposed in the semi-arid tropics. The RH equivalents are shown in the figure.

Because the stomata of all the species measured remained fully open throughout the VPD study, photosynthesis rates changed by less than 10%, although transpiration increased more than threefold between 1 and 3 kPa VPD. Consequently, the ratio between transpiration and photosynthesis (transpiration ratio = transpiration/photosynthesis) changed substantially with VPD. Thus, leaves were most efficient in fixing carbon at low VPDs (high humidities). The plants in this particular study were well watered, but in a stress situation, stomata begin to close and, as discussed later, the situation is quite different.

Water-Use Efficiency in Well-Watered Plants

We now consider how water-use efficiency changes as leaves age and when they are

Table 1. Changes in water use efficiency (ω; $ngCO_2(\mu gH_2O\ kPa\ VPD^{-1})^{-1}$) with leaf age in days.

Age (days)	Pigeonpea	Peanut	Sunflower	Cotton
0-10	18.9 ± 0.7		17.8 ± 0.4	20.0 ± 1.2
10-20	22.0 ± 0.5	22.8 ± 0.7	17.3 ± 0.4	18.1 ±0.5
20-30	20.9 ± 0.5	22.4 ± 0.2	16.6 ± 0.4	17.0 ± 0.3
30-40	19.9 ± 0.8	21.3 ±2.3	15.9 ±0.3	16.3 ± 0.4
40-60	17.9 ± 1.1	18.1 ± 1.4	15.5 ± 0.4	16.3 ±0.9

Sources: Pigeonpea data are the mean of UQ-50 and UQ-68; sunflower data from Rawson and Constable 1980; cotton data from Constable and Rawson 1980a.

exposed to different light levels. Because transpiration ratio, our first index of water-use efficiency, is so sensitive to VPD we use ω, which brings VPD to unity (photosynthesis/transpiration VPD^{-1}), as a second index to examine how conditions other than VPD affect water-use efficiency: ω is explained in Rawson et al. (1977).

Water-use efficiency improved as leaves expanded and then declined significantly as they aged (Table 1). The reduction with aging was approximately 20% in pigeonpea and peanut. It was higher in UQ-50 pigeonpea than in UQ-68. It was also influenced by light (Fig. 3). At very low light levels, leaves of pigeonpea were inefficient, but a plateau was reached at 400 $\mu E\ m^{-2}s^{-1}$ for young leaves and at 200 $\mu\ EM^{-2}s^{-1}$ in old leaves. Thus in pigeonpea we have a species that uses water at least as efficiently as other species when leaves are young and fully illuminated, and one in which efficiency is exceptionally high at low levels of irradiance.

Responses to Water Stress

The main information required in the droughting study of pigeonpea was the rate at which photosynthesis declined as stress increased. In an attempt to simulate field conditions, plants were each grown in 50 kg soil, but the containers were only 750 mm deep, so rooting depth was limited. So that comparisons can be made across studies, the degree of stress is judged here by the leaf water potential as measured in a pressure chamber.

Photosynthesis began to decline at between -10 and -11 bars (1.0 and 1.1 MPa) leaf water potential and by -20 bars was close to zero (Fig.5). Between -25 and -50 bars the leaves respired at a constant rate. All leaves measured were six positions below the unfolding leaf on the main shoot, some 15 to 20 days old, and when plants were rewatered, these leaves all recovered to peak rates of photosynthesis within 36 hours. However, the -50 bar stress

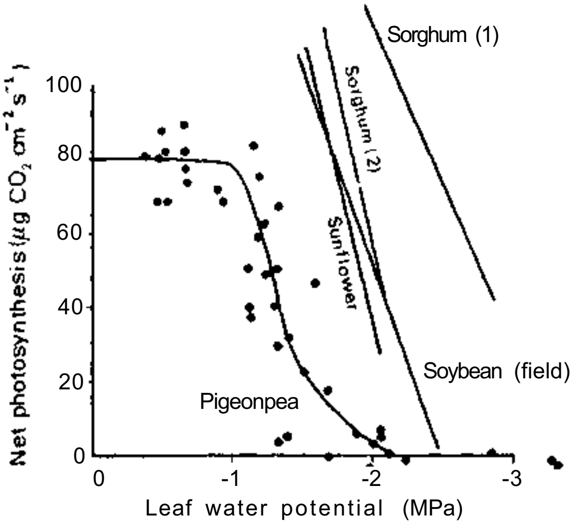

Figure 5. Changes in net photosynthesis with leaf water potential. Data points for pigeonpea are for UQ-50 and UQ-68 and from two experiments. Other data are from:
Sunflower : Rawson (1979)
Soybean : Rawson, Turner and Begg(1978)
Sorghum : Jones and Rawson (1979)

The sorghum curves demonstrate the effects of rate of imposition of stress on photosynthesis where (1) was dried at 0.15 MPalday and (2) was dried at 1.2 MPalday.

was severe enough to result in tip death of some of the branches, losses being restricted to leaves that were unfolding or younger.

The rate of reduction in photosynthesis of 6.1 ngC02 $cm^{-2}s^{-1}$ for each bar leaf water potential between -10 and -20 bars compares with a reduction of 8.5 $ngCO_2$ $cm^{-2}s^{-1}$ per bar for field soybean (Rawson et al. 1978) and 12 $ngCO_2$ $cm^{-2}s^{-1}$ per bar for sunflower (Rawson 1979). Sorghum stressed in bins as described for pigeonpea, but at a rate of 1.5 bars/day, declined at 7 ngC02 cm^{-2} s^{-1} per bar (Jones and Rawson 1979), but as the rate of drying was increased, the rate of reduction in photosynthesis per bar also increased (Fig. 5). Overall, therefore, pigeonpea did not differ markedly from other species in the rate of decline in photosynthesis. It did differ, however, in the rates of photosynthesis current when the decline started, and furthermore the decline started at relatively high water potentials of -10 bars, compared with closer to -15 bars for sorghum, sunflower, and soybean. Thus at -20 bars, pigeonpea leaves were scarcely photosynthesizing while sunflower and soybean leaves were fixing 40 to 60 $ngCO_2$ $cm^{-2}s^{-1}$ and sorghum stressed slowly was fixing more carbon than the unstressed pigeonpea.

These observations indicate that pigeonpea is very sensitive to internal stress and would cease growth when other species were growing rapidly. However, it should be pointed out that the leaf water potential at which photosynthesis started to decline differed with season in sunflower (Rawson 1979). Thus it is conceivable that field-grown plants with deep root systems and slower rates of stress would adapt osmotically and maintain peak rates of photosynthesis to much lower water potentials than observed here. In addition, deep rooting would allow more complete overnight recovery of water potential than was possible in our relatively shallow bins. If continued growth under stress conditions is a priority, then varietal variation in osmotic adaptation should be sought under field conditions.

As the response to water stress by the leaf is to fine-tune its stomatal apertures to maintain internal CO_2 concentrations (Wong et al. 1979), water loss is also reduced. However, the ratio between photosynthesis and transpiration ( ) changes such that water-use efficiency declines. In pigeonpea the 10-bar change in leaf water potential between -10 and -20 bars was accompanied by a reduction i n o f 0.77 ngC02 (µ gH_2O kPa $VPD^{-1})^{-1}$. A 10-bar change in sorghum induced a reduction of 0.60 ngC02 (µ gH_2OkPa $VPD^{-1})^{-1}$ (Jones and Rawson 1979). So, considering the dissimilarities of these two species in other respects, the response of to stress was similar. Of course, in absolute terms, not rate-of-change terms, sorghum fixed twice as much CO2 per unit of water transpired as did pigeonpea.

Diurnal Patterns

To understand how the instantaneous gas exchange patterns we have described for controlled conditions change over a diurnal time scale, we have first to examine how the aerial field enviomment changes over 24 hours. The factors discussed are light, temperature, and VPD, although it is recognized that other factors affect gas exchange. Figure 6a illustrates a fictitious day of 12 hours photoperiod, with a temperature range from 22°C at 0600 hours to 36°C at 1315 hours and clear skies giving an integrated radiation for the 12 hours of about 60E. Vapor pressure was assumed to remain constant at 2.0 kPa; vapor pressures change only marginally over 24 hours during stable weather. VPDs are calculated from thetemperature and VP curves.

In Figure 6b we have used these weather data, the instantaneous photosynthesis versus light data for a young leaf (Fig. 3) and the transpiration versus VPD data (Fig. 4) to generate patterns of gaseous fluxes for leaves at the top of a well-watered crop.

Because photosynthesis is light-saturated at less than one-third full sunlight, leaves were already operating at maximum rates at 0800 hours and rates did not decline until 1600 hours. Early morning transpiration rates were low, however, because temperatures and consequently VPDs were also relatively low. Thus this part of the day was an efficient period as demonstrated bythecurve of transpiration ratio (Transpiration/Photosynthesis). As transpiration followed VPD and photosynthesis was light-saturated for the middle 8 hours of the day, the least efficient period was at 1315 hours in this example (Fig. 6b). At 0700 hours, 50 g water were transpired for each 1g CO2 fixed, whereas at 1315hours, 140 gwaterwere lost per unit CO2 fixed.

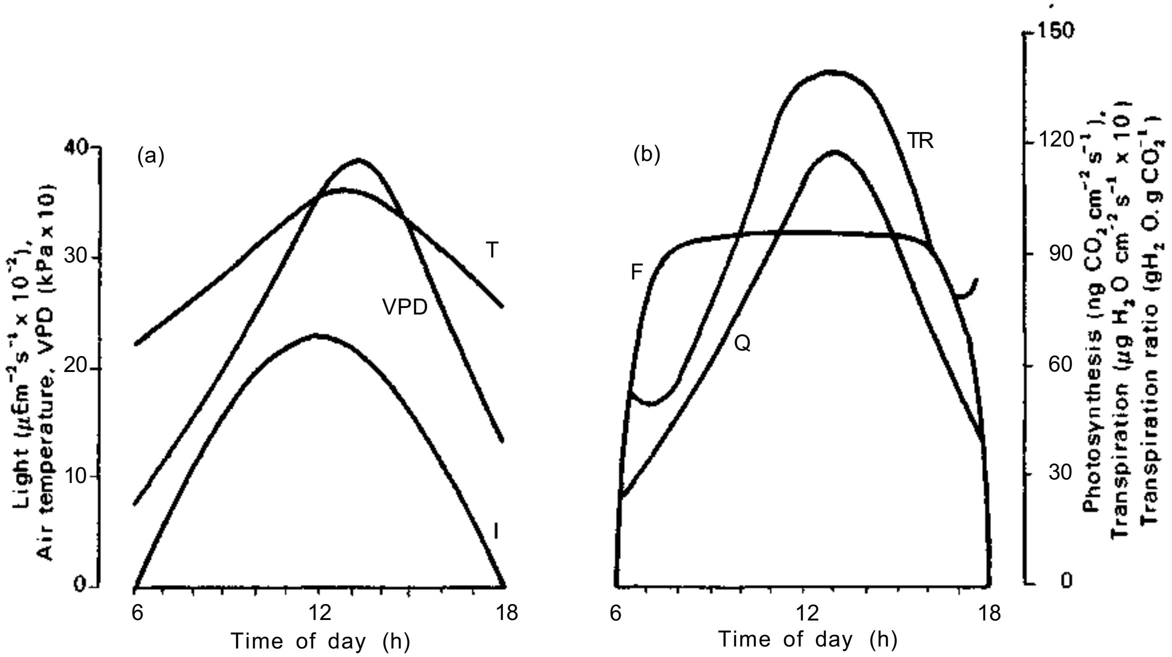

***Figure 6.** (a) Temperature (T), VPD, and light (I) for a summer's day where vapor pressure remained at 2.0 kPa and (b) changes in pigeonpea photosynthesis (F), transpiration (Q) and transpiration ratio (TR = FIQ) for that summer's day assuming that there was no stomatal closure.*

Clearly, the patterns illustrated will change as the crop becomes short of water and the stomata begin to close. Figure 7 demonstrates the changes measured in upper leaves of a soybean crop grown in northern New South Wales, Australia (Constable and Hearn 1978). The first part of the figure shows the nonstress situation, similar to that already described for our simulated leaf (Fig. 6b). In Figure 7b, the fine-tuning of stomata at 0900 hours and thereafter enabled the leaf to restrict its water loss to about 10 μg $cm^{-2}s^{-1}$ in spite of increasing VPD. This, of course, also reduced the influx of CO_2 into the leaf—progressively with further stomatal closure — and it was only after 1400 hours, when VPDs again started to decline, that there was partial recovery of photosynthesis. Figure7c shows the effects on photosynthesis of the leaf further restricting water loss and the final figure illustrates leaves close to death and losing control of transpiration. During this sequence, daily minimum leaf water potentials became progressively more negative, and recovery overnight became less complete.

The general point that arises here is that any reduction in water loss by the leaf, achieved by a reduction in stomatal aperture, results in a decline in carbon fixation, and that the major driving force is VPD. In the soybean studies, for example, short periods of cloud would reduce leaf temperature and effective VPD and actually increase photosynthesis rate by permitting wider stomatal apertures for the same transpiration rate.

Our soybean data (Fig. 7a) confirm the proposal from Figure 6b that the middle part of the day is inefficient for carbon fixation. Transpiration ratios for each 2-hour period were 85 (0800-1000), 135 (1000-1200), 156 (1200-1400), and 123 (1400-1600); the leaf was twice as efficient at 0800 to 1000 as at 1400 to 1600 h. However, when stomatal closure occurs during this inefficient midday period and water is saved, the leaf actually becomes marginally *less* efficient. For the 4-hour period between hours, stomatal closure in Figure 7c reduced transpiration by 45% compared with leaves in Figure 7a, but carbon fixation was reduced by 55%. Reduced efficiency arises because the restriction of water loss also reduces evaporative cooling and leaf temperatures rise. This in turn increases VPDs and more water is trans-

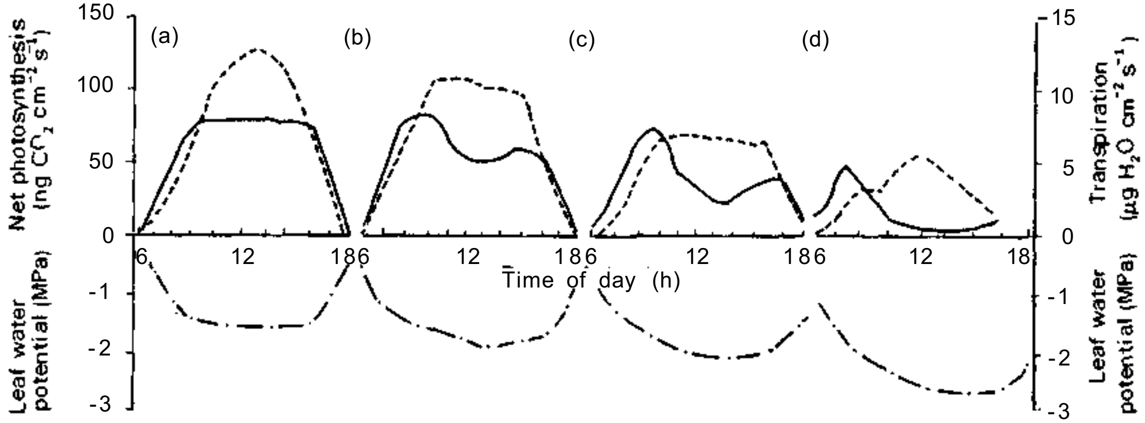

Figure 7. Changes in photosynthesis (solid line), transpiration (dashed line) and leaf water potential for soybean leaves exposed to increasing water stress in the field. The crop received no rain or irrigation for (a) 1 week (b) 2 weeks (c) 4 weeks (d) 5 weeks. Leaves in Figure 7d died shortly after the measurement day. Gas exchange data are from Rawson, Turner and Begg (1978); leaf water potential data from Turner et al. (1978).

pired per unit stomatal aperture. Leaf temperature has a much smaller effect on the influx of CO2 per unit stomatal aperture.

The discussion around Figure 6 ignored the effects of leaf orientation on photosynthesis, transpiration, and water-use efficiency. One of the distinguishing features of legume leaves is their suntracking (diaphotonastic) behavior when leaves are turgid (e.g., Shackel and Hall 1979 for cowpea) and their orientation parallel to the sun's rays when they are stressed. In sparse canopies, diaphotonastic leaf movements can increase carbon fixation in the early hours of the day by increasing light interception by the leaf (Rawson 1979) and, because this is a period of low VPD, can improve the plant's water economy. Sun avoidance can also improve water economy by reducing leaf temperatures (Stevenson and Shaw 1971 for soybean), thus allowing stomata to open wider for the same transpiration rate with consequent increases in CO2 fixation (Rawson 1979).

A Carbon Model for Pigeonpea

Leaf Area

Before building the instantaneous and diurnal patterns of gas exchange into a seasonal time scale, we have to consider the effect that leaf area has on carbon fixation. Dry-matter production is dependent first on carbon production, which is photosynthesis rate x leaf area, and second on carbon loss through respiration. Thus, in a sparse crop, a 20% increase in area per leaf can substitute for a 20% lower photosynthesis rate to yield the same dry matter. In fact, in different varieties of a crop with similar rates of photosynthesis, yield can be dependent on leaf area (e.g. Rawson et al. 1980 with sparse crops of sunflower). An ability to continue generating leaf area under adverse conditions may therefore be as important in the production of dry matter and yield as maintaining high rates of photosynthesis.

Recently, with the greater availability of computers, more detailed attention has been paid to the mechanics of change in area per leaf. Use of the Richard's function (e.g., Richards 1969; Elston et al. 1976; Dennett et al. 1978) or a modified monomolecular function[1] (e.g., Constable and Rawson 1980b) has allowed the expansion of the leaf to be divided into its component parts, namely its duration of expansion and its average growth rate. This method of appraisal makes comparisons possible between cultivars in their responses to water stress. Current commercial cultivars of sunflower, for example, respond to water stress by reducing the average expansion rate of

1. A fortran listing of this program, which permits processing of large batches of leaves, is available from the authors on request.

leaves without changing the period for which leaves expand (Rawson et al. 1980). By contrast, an examination of a collection of exotic sunflowers showed a range of strategies in the response of expansion to stress, which holds promise for breeding (Rawson et al. unpublished data).

The general observation has been that leaf expansion is curtailed considerably earlier in stress than is photosynthesis rate (reviewed by Turner and Begg 1978) and in sunflower, leaf expansion appears to stop at -7 to -10 bars leaf water potential during the day and at about -4 to -6 bars at night (Takami et al. 1981). However, the last study indicated that recovery of leaf expansion after stress may differ between cultivars, and if this also applies in pigeonpea, selection of cultivars that recover rapidly could be profitable. Having enough leaf area at the site of utilization of carbon (i.e., near the pods) is suggested later in this paper as being importantto yield, so plasticity in the area of key leaves over an extended period would be desirable.

Unfortunately, the current work did not include a detailed study of leaf area expansion in pigeonpea. It was observed that under our conditions leaves grew from 5 to 95% of their final area in 18 to 22 days and that average rates of expansion were from 4 to 6 cm^2/day, much slower than for sunflower (Rawson et al. 1980). Rates of leaf appearance on the main shoot were also slower than in sunflower at 0.7 and 0.5 leaves per day for UQ-50 and UQ-68 pigeonpea respectively. This, however, was approximately double the rate for peanut grown concurrently (0.20 leaves/day).

The Model

The rules that follow were the basis of the model, which has been adapted from that described in Constable and Rawson (1980b). The values or patterns in 1, 2, 3, 4, 5, and 10 were determined from ICRISAT annual reports as well as our own data.

1. Each leaf grows according to the modified monomolecular curve and has a duration of 20 days and a specific leaf weight of 4 mg cm^2.
2. The leaf: stem ratio is 46.7%, with stem growth displaced in time from related leaf growth by 5 days.
3. The main shoot reaches an absolute maximum of 45 nodes with potential branching sites between nodes 15 and 40.
4. Maximum area of leaf *at* any node is 80 cm^2, and smaller leaves occur at the base and apex of the plant than in the middle.
5. Leaf number along the branches does not exceed 9 and area per leaf reduces distally along the branches from 0.5 in the area of the related mainshoot leaf to 0.31 at position six.
6. Rate of photosynthesis (Fig. 2a) and respiration (Constable and Rawson 1980a) are related to leaf age and light (Fig. 3) with the initial slope of the light-response curve being 0.39 $ngCO_2$ $(\mu Em^{-2})^{-1}$, as calculated from the fitted curve.
7. Export of photosynthate from a leaf is calculated as that carbon remaining from (Photosynthesis x area of leaf) - (growth and branch requirement). Export from nodes is the sum of these smaller units.
8. Prior to flowering, all carbon remaining aftergrowth requirements are satisfied is exported *to* the roots, where the respiration rate has been set at .50 to support nodules (Pate and Herridge 1978). After flowering, the export of carbon to the roots is sufficient only to maintain the roots.
9. The first flowers appear once the last mainstem leaf unfolds and new leaf initiation stops atthis point. The requirement for carbon of each pigeonpea flower or pod is 6.22 mg C day^{-1}.
10. Once flowering commences, the growth of up to eight new pods per day can be started only if carbon is available; once started, the pod fraction of the canopy grows atthe potential rate or atthe rate of supply of carbon from photosynthesis.
11. These plants did not suffer any water stress.

The model assumes that growth is driven solely by carbon production, and that new organs such as leaves, branches, and effective flowers are generated only when daily carbon production exceeds that quantity necessary to support the growth and respiration of existing organs. Calculation of carbon production depends on the light reaching the leaf and the age of the leaf. As on any day the light level at the leaf changes with time and leaf position in the canopy, these factors are calculated for each leaf on the plant for each day.

Budget for a Leaf

Figure 8 shows predicted carbon relations for a leaf throughout its life for plants grown in 12-hour days with radiation at midday of 2000 μ $Em^{-2}s^{-1}$. The leaf becomes autonomous and a net exporter of carbon at 5 days after unfolding and makes its peak contribution of about 60 $mgCday^{-1}$ 25 days after unfolding. Its exporting period ceases at shortly after day 70. At day 15, leaf growth and respiration account for 10% of carbon produced, but from day 25 onwards, dark respiration only uses 1 to 2% of the carbon produced. Growth and respiration of the stem associated with each leaf account for 20% of the leaf's carbon production. All leaves on the plant follow a similar pattern to that of Figure 8, but the decline after day 25 is less pronounced in leaves produced high on the plant, where mutual shading is minimal.

Budget for a Branch

Figure 9 illustrates the carbon relations of a branch in the middle of the plant profile (node 28) on plants sown at 5 m^{-2} and exposed to the same light conditions used in Figure 8. The model generated this node about 7 weeks from plant emergence and the branch had carbon in excess of its maintenance and growth requirements when it was 8 days old, but the requirement for carbon within the branch increased progressively as pods were set. Under the stated conditions, the branch produced about ten pods. This branch was chosen for illustrative purposes; the model produces branches of different architecture depending on carbon availability.

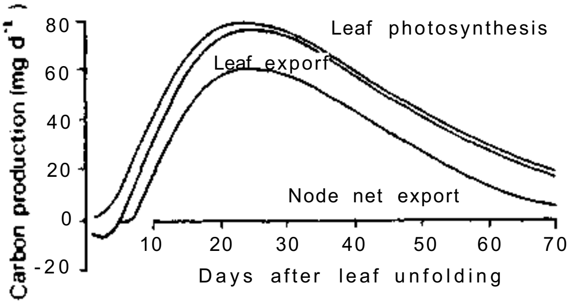

Figure 8. Calculated carbon production by a pigeonpea leaf and carbon available for export from the leaf and its node as the leaf ages. A node is the leaf plus its related stem. This model assumes a day-length of 12 hours with light at midday of 2000 μ E $m^{-2}s^{-1}$, a maximum area per leaf of 80 cm^2, and a duration of leaf expansion of 20 days. Stem growth is related to leaf growth, but displaced by 5 days.

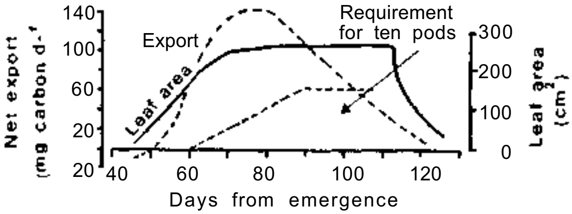

Figure 9. Calculated carbon budget for a branch of pigeonpea throughout its life. The calculations are for a branch at node 28, in the middle of the plant, using light conditions as in Figure 8, it assumes 5 plants per m^2 and a maximum area per leaf of 80 cm^2.

Budget for a Plant

The production of dry matter for a plant "grown" under the radiation environment described for the leaf budget, and in a plant stand of 5 nv^2, is shown in Figure 10. Leaf area index reached a maximum of 3.7 at 80 days from seedling emergence and the yield was 2.7 tonnes/ha from 264 pods per plant. Shoot: root ratios ranged from 3 to 11 during the season, and harvest index was .22 at maturity.

All these values, apart from yield, fall within the range observed in pigeonpeas (Sheldrake and Narayanan 1979; Natarajan and Willey 1980). However, when the model was run with different conditions (Table 2), that is at reduced light levels, and using light measured over the 1978-79 season at ICRISAT, leaf areas were relatively unresponsive, as was yield. This result may not be nonsensical because pigeonpea leaves saturate at such low light levels (Fig. 3). But as we have no data on how leaf expansion

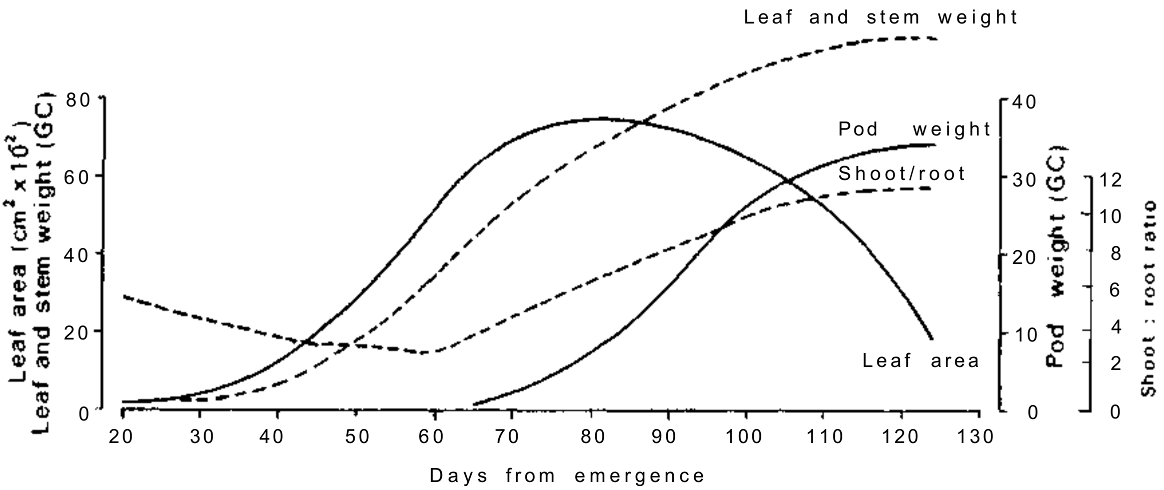

Figure 10. Output generated by the model for a plant assuming a population of 5 plants per m^2 and light conditions as in Figure 8. Other characteristics of these plants are shown in Table 2.

Table 2. Data from the modal of growth of pigeonpea under thraa light conditions in constant 12-hour days.

	2000 μ E $m^{-2}s^{-1}$ (peak)	1000 μ E $m^{-2}s^{-1}$ (peak)	ICRISAT 1978-79 (measured seasonal light conditions)
Leaf area (cm^2/plant)	7409	7095	7380
Shoot: root ratio (at mid pod-fill)	8.2	12.2	9.3
Pods/plant	264	208	240
Pod weight (g carbon/plant)	33.8	28.1	31.2
Grain yield (t/ha) (63% of pods)	2.67	2.22	2.46

patterns and final leaf size are affected by light we have no basis on which to modify the model.

As this model in its untuned form appears to be fairly accurate, it can be used to formulate hypotheses about the pigeonpea plant. Clearly it has major weaknesses because there is insufficient knowledge about the pigeonpea plant, and because the authors' familiarity with the crop is limited. One particular gap in knowledge relates to growth of the roots and respiration by roots and nodules. The work of Pate and Herridge (1978) suggests massive losses of carbon through root respiration as does that of Lambers (1979), but it seems that data for pigeonpea are not available. We have assumed that root growth is reduced at flowering, but this may not be the case. The model fails also in taking no account of temperature. At lower temperatures, for example, photosynthesis will be little affected but leaf size will be increased. Thus the model should simply be treated as an exercise in assembling patterns, but it can be improved in step with knowledge.

Interpretation of the Budget Predictions

One of the confusing aspects of pigeonpea and many other legumes is the low retention of flowers to form pods. The model predicts that at the time of flowering, branches are producing far more carbon than is required to support the respiration and growth of a multitude of flowers (Fig. 9). In fact if all carbon fixed after flowering was put into pods, the yield would be about 1.8 times higher. There are at least three explanations for this poor pod setting. The first is a traditional favorite — hormones; the second assumes that other organs are competing successfully with the flowers for this carbon, and the third, a modification of the second, assumes that the carbon cannot be moved to the flowers rapidly enough because of limitations in the vascular supply. Thus, in the third option, the plant cannot be considered a pool of carbon from which all sinks can draw equally.

We now consider the likelihood of the third option applying to pigeonpea. Flowers may be positioned several centimeters from the nearest leaf, and carbon has to move along this pathway to sustain the flowers and young pods. Movement will be by diffusion, at least through the flower pedicel, because at flowering vascular differentiation will not have occurred (Milthorpe and Moorby 1969). If we assume that a flower pedicel, and therefore the minimum diffusion pathway, is 1 cm long (X in the following equation) and that its cross-sectional area (A) through which diffusion can occur is 0.01 cm^2, we can calculate the flux of sucrose (F) and/or the concentration gradient (AC, g sucrose cm^{-3}) required to support a flower from Fick's first law of diffusion (e.g. Nobel 1974).

$$F = DA \frac{AC}{AX} \text{ g sucrose day}^{1}$$

where D is the diffusion coefficient of sucrose through water (0.521 x $10^{-5} cm^2 s^{-1}$, or 0.432 cm^2 day^1. A pigeonpea flower of dry weight 0.34 g respiring at the rate measured for a cotton flower (Constable and Rawson 1980c) requires 1.5 mg C day^{-1}. To maintain such a flux, the concentration gradient should be 0.83g sucrose cm^{-3}.

The leaf nearest a flower raceme produces about 30 mg C/day (such a leaf would be about half the area of the example in Fig. 8). If the branch volume at this point were 0.5 cm^3, a concentration gradient (A C) of 0.136 g sucrose cm^{-3} would apply. Thus to maintain the sucrose gradient of 0.83 g cm^{-3} calculated above through one flower pedicel would require the carbon production of at least 6 such leaves, which is equivalent to that of a whole branch. On the basis of these calculations, the vascular limitation ensures that only one new flower per day can set a pod on each branch even under ideal conditions; other flowers abort through lack of carbon.

This proposed bottleneck to yield has its advantages. Once pods are set and the vascular system is operational, the availability of carbon for pod growth (now from a larger carbon pool) will be governed only by the potential of the seeds to grow. Thus early conservatism will result in uniform final seed size and assured success for the next generation. To a degree, this approach will also buffer yield across a range of conditions and in good seasons permit more material to be stored in stem reserves, which can be drawn on later.

According to this hypothesis on pod setting and growth, which also fulfills the requirements of Sheldrake's (1979) hydrodynamic model, one way to increase the potential yield in pigeonpea is to position flowers closer to the sources of assimilation, i.e., axillary flowers. A second approach would be to select for short pedicels with large cross-sectional area; these would have a lower resistance to the movement of assimilates. A third selection criterion would be large leaves along the branches; these would fix more carbon and increase the concentration gradients proportionately. These modifications would result in more pod set, but less buffered yield, because growth rates of individual pods would be more directly dependent on the environment during pod fill. Thus, they would change the crop from one ideally suited to peasant agriculture to one designed solely for relatively high seed yields.

While this model may have helped our understanding of pigeonpea, it is based on measurements made on only two cultivars of pigeonpea grown in a glasshouse. If our understanding of the carbon budgeting of pigeonpea is to be increased, it is essential that the type of measurements outlined in this paper should be extended to far more diverse material grown in the field. Data on other aspects are required for a fuller understanding of the whole system:

1. Data on the contribution of the pod to its own carbon requirements. In soybean, up to 40% of the respiratory requirements of the pod may be met by photosynthesis of sunlit pods (Rawson et al. 1978) and similar values may apply to pigeonpea.
2. Leaf growth patterns under varying conditions. How does light availability, for example, affect the profiles of leaf area and the expansion of individual leaves?
3. Precise measurements of plant morphology. Are the patterns of branching and leaf

production in the strict relationships proposed by Harper and Bell (1979) for other species? Are the timings of appearance of each organ strictly related?

4. Do light extinction coefficients for pigeonpea crops match those for other crops?
5. What are the leaf: stem ratios for different parts of the plant and how are they influenced by the environment?
6. Does vascular development of flowers and pods follow the patterns assumed above; i.e., development of vascular strands only after the growth of the young pod commences?
7. What are the distribution patterns of carbon from the leaves to the flowers? This could be readily researched using C^{14}.
8. What values should be assigned to root growth and respiration under different conditions?

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References

BHAGSARI, A. S., and BROWN, R. H. 1976. Photosynthesis in peanut (*Arachis*) genotypes. Peanut Science 3: 1-5.

CONSTABLE, G. A., and HEARN, A. B. 1978. Agronomic and physiological responses of soybean and sorghum crops to water deficits. I. Growth, development and yield. Australian Journal of Plant Physiology 5: 159-167.

CONSTABLE, G. A., and RAWSON, H. M. 1980a. Effect of leaf position, expansion and age on photosynthesis, transpiration and water use efficiency of cotton. Australian Journal of Plant Physiology 7: 89-100.

CONSTABLE, G. A., and RAWSON, H. M. 1980b. Carbon production and utilisation in cotton: inferences from a carbon budget. Australian Journal of Plant Physiology 7: 539-553.

CONSTABLE, G. A., and RAWSON, H. M. 1980c. Photosynthesis, respiration and transpiration of cotton fruit. Photosynthetica. (In press).

DENNETT, M. D., AULD, B. A., and ELSTON, J. 1978. A description of leaf growth in *Vicia faba* L. Annals of Botany 42: 223-232.

EHLERINGER, J., and BJORKMAN, O. 1977. Quantum yields for CO_2 uptake in C3 and C4 plants: dependence on temperature, CO2 and O2 concentration. Plant Physiology 59: 86-90.

EL-SHARKAWY, M., HESKETH, J. D., and MURAMOTO, H. 1965. Leaf photosynthetic rates and other growth characters among 26 species of *Gossypium.* Crop Science 5: 173-175.

ELSTON, J., KARAMANOS, A. J., KASSAM, A. H., and WADSWORTH, R. M. 1976. The water relations of a field bean crop. Philosophical Transactions of the Royal Society, London, B. 273: 581-591.

EVANS, L. T, and DUNSTONE, R. L. 1970. Some physiological aspects of evolution in wheat. Australian Journal of Biological Sciences 23: 725-741.

HARPER, J. L., and BELL, A. D. 1979. The population dynamics of growth form in organisms with modular construction. Pages 29-52 *in* Population dynamics, eds. R. M. Anderson, B. D. Turner, and L. R. Taylor., Blackwell.

HORIE, T, and UDAGAWA, T 1971. Canopy photosynthesis of sunflower plants — its measurements and modelling. Bulletin of the National Institute of Agricultural Science (Japan) series A, 18: 1-54.

JONES, M. M., and RAWSON, H. M. 1979. Influence of rate of development of leaf water deficits upon photosynthesis, leaf conductance, water use efficiency, and osmotic potential in sorghum. Physiol. Plant. 45: 103-111.

LAMBERS, J. T. 1979. Energy metabolism in higher plants in different environments. Ph. D. Thesis, University of Groningen.

LLOYD, N. D. H., and CANVIN, D. T. 1977. Photosynthesis and photorespiration in sunflower selections. Canadian Journal of Botany 55: 3006-3012.

LUSH, W. M., and RAWSON, H. M. 1979. Effects of domestication and region of origin on leaf gas exchange in cowpea (*Vigna unguiculata* [L] Walp.) Photosynthetica. 13: 419-427.

MILTHORPE, F. L, and MOORBY, J. 1969. Vascular transport and its significance in plant growth. Annual Review of Plant Physiology 20: 117-138.

NATARAJAN, M., and WILLEY, R. W. 1980. Sorghum-pigeonpea intercropping and the effects of plant population density. I. Growth and yield. Journal of Agricultural Science. (In press.)

NOBEL, P. S. 1974. Introduction to biophysical plant physiology: London and New York: W. H. Freeman.

PATE, J. S., and HERRIDGE, D. F. 1978. Partitioning and utilization of net photosynthate in a nodulated legume. Journal of Experimental Botany 29: 401-412.

PATHAK, G. N. 1970. Red gram *(Cajanus cajan* [L] Millsp.) pages 14-53*in* Pulse crops of India (ed. P. Kachroo), New Delhi, India: Indian Council of Agricultural Research.

RAWSON, H. M. 1979. Vertical wilting and photosynthesis, transpiration and water use efficiency of sunflower leaves. Australian Journal of Plant Physiology 6: 109-120.

RAWSON, H. M., and CONSTABLE, G. A. 1980. Carbon production of sunflower cultivars in field and controlled environments. I. Photosynthesis and transpiration of leaves, stems and heads. Australian Journal of Plant Physiology 7: 555-573.

RAWSON, H. M., and HACKETT, C. 1974. An exploration of the carbon economy of the tobacco plant. III. Gas exchange of leaves in relation to position on the stem, ontogeny and nitrogen content. Australian Journal of Plant Physiology 1: 551-560.

RAWSON, H. M., and WOODWARD, R. G. 1976. Photosynthesis and transpiration in dicotyledonous plants. I. Expanding leaves of tobacco and sunflower. Australian Journal of Plant Physiology 3: 247-256.

RAWSON, H. M., BEGG, J. E., and WOODWARD, R. G. 1977. The effect of atmospheric humidity on photosynthesis, transpiration and water use efficiency of leaves of several plant species. Planta (Berl.) 134: 5-10.

RAWSON, H. M„ TURNER, N. C, and BEGG, J. E. 1978. Agronomic and physiological responses of soybean and sorghum to water deficits. IV. Photosynthesis, transpiration and water use efficiency of leaves. Australian Journal of Plant Physiology 5: 195-209.

RAWSON, H. M., CONSTABLE, G. A., and HOWE, G. N. 1980. Carbon production of sunflower cultivars in field and controlled environments. II. Leaf growth. Australian Journal of Plant Physiology 7: 575-586.

RICHARDS, F. J. 1969. The quantitative analysis of growth. Pages 3-76 *in* Plant physiology, a treatise. Volume VA, ed. F. C. Steward, New York and London: Academic Press.

SHACKEL, K. A., and HALL, A. E. 1979. Reversible leaflet movements in relation to drought adaptation of cowpeas (*Vigna unguiculata* [L.] Walp.). Australian Journal of Plant Physiology 6: 265-276.

SHELDRAKE, A. R. 1979. A hydrodynamic model of pod set in pigeonpea *{Cajanus cajan).* Indian Journal of Plant Physiology 22: 137-143.

SHELDRAKE, A. R., and NARAYANAN, A. 1979. Growth, development and nutrient uptake in pigeonpeas *{Cajanus cajan).* Journal of Agricultural Science (Cambridge) 92: 513-526.

SHELDRAKE, A. R., NARAYANAN, A., and VENKATA-RATNAM, N. 1979. The effects of flower removal on seed yield of pigeonpeas *{Cajanus cajan).* Annals of Applied Biology 91(3): 383-390.

STEVENSON, K.R., and SHAW, R. H. 1971. Effects of leaf orientation on leaf resistance to water vapour diffusion in soybean (*Glycine max* [L.] Merr.) leaves. Agronomy Journal 63: 327-329.

TAKAMI, S., TURNER, N. C, and RAWSON, H. M. 1981. Influence of water deficits on leaf expansion in sunflower (*Helianthus annuus* [L.]) cultivars. Plant, Cell and Environment. (In press.)

TURNER, N. C, and BEGG, J. E. 1978. Response of pasture plants to water deficits. Pages 50-66 *in* Plant relations in pastures (ed. J. R. Wilson). Melbourne: CSIRO.

TURNER, N. C, BEGG, J. E., RAWSON, H. M., ENGLISH, S. D., and HEARN, A. B. 1978. Agronomic and physiological responses of soybean and sorghum crops to water deficits. III. Components of leaf water potential, leaf conductance, $^{14}CO2$ photosynthesis, and adaptation to water deficits. Australian Journal of Plant Physiology 5: 179-194.

WONG, S. C, COWAN, I. R., and FARQUHAR, G. D. 1979. Stomatal conductance correlates with photosynthetic capacity. Nature (London) 282: 424-426.

WOODWARD, R. G., andR AWSON, H. M. 1976. Photosynthesis and transpiration in dicotyledonous plants. II. Expanding and senescing leaves of soybean. Australian Journal of Plant Physiology 3: 257-267.

Nitrogen Fixation by Pigeonpea

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Abstract

Pigeonpea yields have been increased up to 22% by 200 kglha fertilizer nitrogen, suggesting that nitrogen fixation by nodules is not always enough to meet the nitrogen requirements of the crop under field conditions. Nitrogen fixation by pigeonpea estimated by measuring total nitrogen uptake, in comparison with a nonlegume, indicated that pigeonpea could fix up to 69 kg N/ha per season, which amounts to 52% of the total nitrogen uptake. Fixation by pigeonpea increased with crop duration, but there were differences within a maturity group. In one experiment with maize following pigeonpea, the residual nitrogen was estimated to be approximately 40 kglha. Allantoin, one of the nitrogen transport compounds associated with nodulated legumes, appears to be a useful indicator of nitrogen-fixing activity of pigeonpea.

Nitrogen fixation of pigeonpea has been examined at ICRISAT through a variety of techniques, and the limitations of some of the descriptive and measured criteria on inoculation response are discussed elsewhere (Thompson et al. these Proceedings). Unfortunately, there are particular problems with the very useful, but destructive and time-consuming, acetylene reduction technique for nitrogenase assay of pigeonpea; hence, alternative methods are particularly desirable with this species.

Nitrogen Supply

To test whether the nitrogen supply to pigeonpea plants was limiting growth and yields, we compared unfertilized plants with plants fertilized with (1) a small amount of nitrogen fertilizer (20 kg N/ha) and (2) a liberal dose of fertilizer (200 kg N/ha), which should have been more than enough to satisfy the nitrogen demand of the crop. The response to fertilization varied with year and soil type.

Table 1. Effect of fertilizer nitrogen on pigeonpea cv ICP-1 grain yield in Vertisols and Alf isols (rainy season).

Fertilizer N applied (kg/ha)	Vertisol (1979)		Alfisol (1977)	
	Shoot dry wt (kg/ha)	Grain yield (kg/ha)	Shoot dry wt (kg/ha)	Grain yield (kg/ha)
0	8 725	1 834	2 564	850
20	8 425	1 885	3 147	970
200	10 929	2 234	3 560	970
LSD (5%)	1 033	305	401	105
CV (%)	13.0	18.1	24.2	8.8

Generally, nitrogen fertilizing increased early plant growth in both Vertisol and Alfisol fields up to 65 days after planting, but final yield was only increased in 1 out of 3 years' trials on each soil (Table 1).

The lack of response to nitrogen fertilizer in some seasons may have been due to loss of fertilizer through volatilization of ammonia and denitrification, reducing the effective level of nitrogen available for plant uptake, or else factors other than nitrogen supply may have limited growth. Ensuring that added nitrogen fertilizer is available to plants growing for 120

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days on residual moisture is not easy, as fertilizer nitrogen applied at the surface as a split dose, near the end of the rainy season, may not be available to the active roots, which may be 1 m or more deep in the soil. Pigeonpea grown in both Alfisols and Vertisols has also not responded to foliar sprays of urea given after the rains ceased (I. M. Rao, ICRISAT, unpublished observations).

Addition of 20 kg N/ha in the Alfisols increased yields as much as the large N dose (Table 1), although the total nitrogen uptake was only increased by 13 kg N over the unfertilized treatment; even 200 kg N only increased total uptake by 28 kg N/ha. There was no effect of the 20 kg N in the Vertisol. On the market value prevailing then, this increase in yield with 20 kg N in the Alfisols was worth Rs. 321, with a fertilizer cost of Rs. 67, a cost-benefit ratio of 4.8:1.

In an experiment on Alfisols in 1977, the addition of nitrogen fertilizer at the rate of 100 kg N/ha reduced nodule formation by 47%, nodule weight per plant by 74% at 20 days, and nitrogenase activity per plant by 86%. However, by 60 days after planting, there were no differences between fertilized and unfertilized plants (Table 2). A similar reduction in nodulation and increase in plant dry weight with 200 kg N/ha was also observed in a Vertisol. There seems to be relatively little lasting inhibition of pigeonpea nodulation by combined nitrogen in these soils. Nodulation of plants grown in sand culture and continually supplied with combined nitrogen was not inhibited at a concentration of 25 ppm N as nitrate.

It may be that pigeonpea cultivars vary in their response to combined nitrogen as in a further study in sand culture, however, pigeonpea nodulation and nitrogenase activity were depressed by 25 ppm N as nitrate and were slightly less tolerant than *Phaseolus vulgaris* and *Vigna unguiculata* (Table 3). These observations are in agreement with those of Quilt and Dalai (1979), who found that pigeonpea nodulation was inhibited in loamy soils with 50 ppm nitrate in the rainy season in Trinidad. The inhibition was not observed in the same soil in an irrigated crop grown in the dry season (J. M. Day, unpublished observations). It is possible that waterlogging in the rainy season, and not nitrate, may have induced premature nodule senescence. Nodule senescence is rapid in Vertisols and Alfisols at Hyderabad when they become saturated, and since this occurs more frequently on Vertisols, it could account for the

Table 2. Effect of fertilizer nitrogen on pigeonpea cv ICP-1 nodulation, nitrogenase activity, and top growth in Alfisols, rainy season 1977.

Fertilizer N applied (kg/ha)	Nodule no./ plant	Nodule dry wt (mg)	N_2-ase activity µ mol C_2H_4/hour/		Shoot dry wt (g)
			plant	g nodule dry wt	
			20 days after planting		
0	17	19	3.65	459	0.28
20	12	8	1.69	282	0.35
100	9	5	0.51	205	0.33
LSD (5%)	5	NS	0.52	158	NS
CV(%)	33.8	150	20.7	38.9	14.9
			60 days after planting		
0	39	351	21	77	18.8
20	36	344	18	54	24.8
100	42	369	18	53	28.3
LSD (5%)	NS	NS	NS	NS	5.9
CV (%)	38.6	32.5	43.2	41.5	19.1

Table 3. Effect of combined N on growth, nodulation, and nitrogenase activity of *Cajanus cajan* cv UWI-17, *Phasaolus vulgaris* cv Jamapa and *Vigna unguiculata* cv K-2809 (long-duration spreading variety) grown in nitrogen-free medium.

	Irrigated with solutions containing (ppm N)					
	0	25	50	75	100	150
			Cajanus cajan			
Top dry wt (g/plant)	2.65	3.23	3.47	3.84	3.62	3.71
Nodule dry wt (mg/plant)	170	128	41	29	15	0
Nitrogen ase(μmolC_2H_4/plant/hr)	11.8	8.4	3.2	2.1	0.6	0
			Phaseolus vulgaris			
Top dry wt (g/plant)	3.63	5.38	6.52	6.52	6.64	
Nodule dry wt (mg/plant)	188	113	67	33	7	
Nitrogenase (*μ* mol C_2H_4/plant/hr)	12.8	18.5	13.2	3.41	1.01	
			Vigna unguiculata			
Top dry wt (g/plant)	4.29	5.81	7.05	8.29	8.61	
Nodule dry wt (mg/plant)	156	190	110	93	27	
Nitrogenase (μ mol C_2H_4/plant/hr)	10.9	11.5	6.6	4.6	2.1	

poorer nodulation observed during the rainy season in Vertisols.

Nitrogen Fixation

It is difficult to measure nitrogen fixation by pigeonpea grown in the field, because it is difficult to estimate nitrate uptake by such a long-duration and deep-rooted crop. Sheldrake and Narayanan (1979) measured nitrogen uptake for three medium-duration cultivars at ICRISAT Center, on a Vertisol and an Alfisol. They showed that there was little nitrogen uptake after 120 days' growth and that a substantial amount of nitrogen was present in leaf fall during the season, ranging from 32 to 36 kg N/ha. We attempted to measure available soil nitrogen by growing nonlegumes such as sorghum, maize, sudangrass, or castor for the same period as pigeonpea. If we make the assumption that the roots of nonlegumes explore similar volumes of soil over both time and space, and that both species take up all available soil nitrogen, then nitrogen fixation by the legume can be calculated as total legume nitrogen uptake minus total nonlegume nitrogen uptake. Table 4 shows the results from one such experiment for 11 pigeonpea cultivars of different duration grown in the 1977 rainy season on an Alfisol at ICRISAT Center. In this experiment only one sorghum harvest was made, at 175 days. Thus the value for nitrogen fixation by pigeonpea cultivars of shorter duration (particularly Pant A-3 and Prabhat) is likely to be an underestimate. In addition, the sorghum probably gained nitrogen from nitrogen fixation by bacteria associated with its roots, resulting in an underestimate for all values for pigeonpea nitrogen fixation.

Nitrogen fixation by pigeonpea increased with crop duration, but there were differences between cultivars within a maturity group, e.g., JA-275 fixed only 13 kg N/ha compared with cv T-7, which fixed 69 kg N/ha. Early-duration cultivars apparently fixed little nitrogen, and even for the best fixing cultivar, N_2 fixation represented only 52% of the total nitrogen uptake. The harvest index for nitrogen was also small ranging from 21% to 57%, and decreased with crop duration.

A considerable amount of nitrogen (9 to 28 kg/ha) was lost as fallen leaves, with large differences between cultivars, but with a surprisingly similar and high percentage of nitrogen in these leaves (mean of 1.54%, range from 1.23to 1.68%). The fallen leaves represented 12 to 26% of the total N uptake by the plant. Assuming, as Sheldrake and Narayanan (1979) did, that we recover only 50% of the roots, then for cv BDN-1, fallen leaves and roots plus nodules potentially return 33 kg N/ha to the soil, a figure very similar to the 40 kg N/ha estimated by Sheldrake and Narayanan for ICP-1, a variety

Table 4. **Total nitrogen uptake and fixation by some pigeonpea cultivars on an Alfisol at ICRISAT Canter, rainy season 1977.**

Cultivar	Plant growth habit[a]	Maturity (days)	N yield (kg/ha) Pod with seed	Plant top	Root + nodule	Fallen plant parts	Total N uptake (kg/ha)	Balance against sorghum (N fixed)
Prabhat	DT	115	43.4	11.6	2.7	11.4	69.1	+ 4.4
Pant A-3	DT	115	44.3	14.9	3.9	8.5	71.6	+ 6.9
T-21	NDT	130	55.7	31.1	4.6	16.5	107.9	+ 43.2
UPAS-120	NDT	125	46.1	24.9	5.3	15.5	91.8	+ 27.1
BDN-1	NDT	130	52.3	37.2	4.1	24.6	118.2	+ 53.5
No. 148	NDT	150	53.2	40.9	8.1	17.6	119.8	+ 55.1
JA-275	NDT	170	33.7	19.0	7.5	17.7	77.9	+ 13.2
ICP-7035	NDT	170	33.4	34.7	11.9	21.0	101.0	+ 36.3
ICP-7065	NDT	175	49.0	23.0	7.6	28.1	107.7	+ 43.0
T-7	NDT	215	33.3	64.2	15.3	21.3	134.1	+ 69.4
NP(WR)-15	NDT	240	34.0	54.1	11.5	14.7	114.3	+ 49.6
Sorghum		175	9.5	51.6	3.6	0	64.7	

a. DT - Determinate; NDT = Nondeterminate.

of similar maturity as BDN-1. This could account for the large residual effect of pigeonpea sometimes observed on subsequent crops. The amount of nodule tissue at the end of the season is very low and accounts for less than 0.2 kg N/ha. However, this is an underestimate of the total amount of nitrogen returned to the soil as nodules senesce, since this is a continual process starting about 30 days after planting. Even so, such nodules contain on an average only 3.7% N, much less than that found in active nodules (about 5.5% N).

In the experiment conducted in 1977 to study the effect of nitrogen on pigeonpea in an Alfisol (Table 1) sorghum was used as a nonlegume crop for comparison with the pigeonpea cv ICP-1. Nitrogen uptake (kg/ha) was:

pigeonpea: N_0 102; N_{20} 115; N_{200} 131;
sorghum: N_0 55; N_{20} 68.

Nitrogen fixation by pigeonpea is therefore estimated to be 47 kg/ha, or 46% of total nitrogen uptake at No.

An experiment conducted on a Vertisol field during the 1979 and 1980 rainy seasons indicated the large residual effect pigeonpea could have on a subsequent maize crop. Treatments in 1979 were main plots of sole-crop pigeonpea, intercropped pigeonpea/sorghum (1 row:2 rows) with 0 and 80 kg N/ha, sole-crop sorghum with 0 and 80 kg N/ha, and fallow, with all above-ground parts of the plants removed at harvest (except fallen pigeonpea leaves). In the 1980 season, maize was planted uniformly over the field, with subplots receiving 0, 20, 40, 60 and 80 kg N/ha as fertilizer. Figure 1 shows that

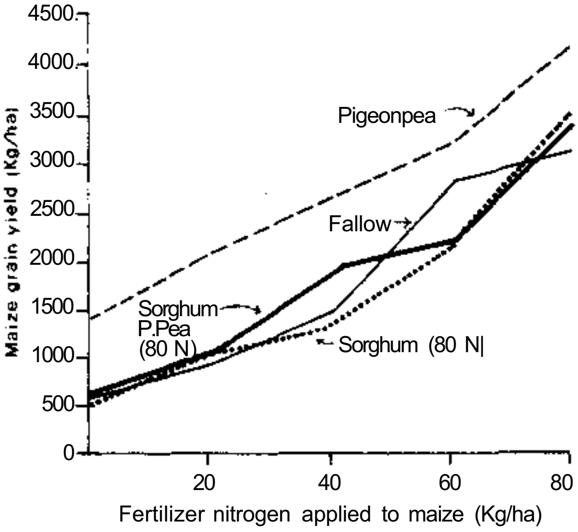

Figure 1. Residual effect of pigeonpea on grain yields of maize (kharif 1980).

sole-crop pigeonpea had a large residual effect on maize yields at all nitrogen levels. Intercrop pigeonpea had surprisingly little residual effect as did sole-crop sorghum fertilized with 80 kg N/ha. Compared with the fallow treatment, the sole pigeonpea supplied an extra 40 kg N to the maize crop. If we make the assumptions that soil nitrogen losses in the form of leaching and denitrification were similar for the fallow and the pigeonpea, and that pigeonpea had no effect on the rate of nitrogen mineralization, then the residual effect of the pigeonpea can be attributed to nitrogen fixation.

We plan to conduct further experiments to differentiate the role of mineralization on pigeonpea residues from that of nitrogen fixation in the residual effect of pigeonpea.

Nitrogenase Activity

The acetylene-reduction technique (Hardy et al. 1968) provides a useful index of N_2 fixation, and has been used to determine the potential nitrogenase activity of field-grown legumes (Hardy and Holsten 1977). Nitrogenase activity of field-grown pigeonpea plants increased during the early growth, with means for seven lines of different duration of 1.7 µmol C_2H_4/plant per hour at 30 days and 93.5 µmol at 85 days (Table 5). From 60 days, cv C-11 and its hybrid with MS-4 generally had higher nitrogenase activity. Because of the difficulty in recovering nodules from the soil, there is a large plant-to-plant variability in nitrogenase activity, resulting in a large coefficient of variation. Unless large numbers of plants are sampled, it is difficult to demonstrate treatment effects even if we take a minimum of ten plants in each of six replicates. The maximum nitrogenase activity of 171 µ mol C_2H_4/plant per hour for the hybrid MS-4 x C-11 is comparable to that of groundnut, but high compared with other grain legumes such as *Phaseolus vulgaris,* chickpea, and cowpea. Specific activity (activity per g of nodule wt.) varied between dates, possibly reflecting differences in photosynthetic activity and carbohydrate availability in the nodules, but there was no consistent difference between cultivars.

The 70-day harvest coincided with overcast days. In other rainy seasons nitrogenase activity has been less, with a maximum of 55 µ mol C2H4/plant per hour.

The nitrogenase activity per plant for pigeonpea grown in a Vertisol are much lower thaninan Alfisol. In the cooler dry season, when pigeonpea was grown in a Vertisol on residual moisture, both nodulation and nitrogenase activity per plant and per gram nodule tissue were small and less than in the rainy season (Table6).

Nitrogen Transport Compounds

The possibility of using the compounds present in the xylem flow exuded after decapitation of the plant as a measure of nitrogen fixation was demonstrated by the studies of Matsumoto et al. (1975, 1976). They showed that 90% of the nitrogen exported from soybean nodules was in

Table S. Seasonal profile of nitrogenase activity (µ mol/plant/hr) of pigeonpea grown on Alfisols, at ICRISAT Center, rainy season 1979.

Cultivar	Duration	Days after planting 30	40	50	60	70	85
ICP-1	Medium	1.9	0.7	3.9	6.7	31.1	78.2
T-21	Early	1.3	0.5	1.1	1.4	25.9	24.8
c-n	Medium	1.0	1.4	7.5	10.1	51.6	132.7
ICP-7035	Late	3.2	1.7	3.9	4.7	51.5	94.3
MS-4x C-11	Medium	1.8	1.5	6.5	8.3	37.6	171.2
MS-3A x 7035R	Late	1.4	1.0	2.8	3.5	44.5	75.2
MS-3A x 7035W	Late	1.3	1.2	3.9	2.1	31.6	78.3
LSD (0.05)		NS	NS	NS	4.9	N S	60.7
CV(%)		101.1	79.4	90.8	78.6	100.2	55.0

Table 6. **Nitrogenase activity of pigeonpea cv ICP-1, 30 and 60 days after sowing in rainy and postrainy seasons at ICRISAT Center, 1976.**

	Nodule no./plant		Nodule dry wt (mg)		μ mol/plant/hr		μ mol/g nodule/hr	
	30 days	60 days	30 days	60 days	30 days	60 days	30 days	60 days
Rainy season								
Alfisol	39	64	79	521	16	55	205	112
Vertisol	29	25	52	87	12	9	317	98
Postrainy season								
Vertisol	12	9	9	52	0.3	2.3	30	43

the form of ureides. Ureides also predominated in the xylem exudate of nodulated nitrogen-fixing soybeans, but the levels were minimal in the xylem sap of a nonnodulated isoline. These studies suggested a close link between the forms of nitrogenous compounds transported in the xylem sap and the nodulation status of the plant.

When the soil is adequately moist, xylem sap exudes from the stem of pigeonpea for at least 1 hour after cutting in the hypocotyl region. In the sap of 50-day-old plants of cv ICP-1 growing in an Alfisol at ICRISAT, ureides were the main nitrogenous compounds, amounting to 57% of the total soluble Kjeldahl N. Amino acids and amides amounted to 37%, the remainder being predominantly nitrate.

We examined the effect of increasing nitrogen levels in the growth medium on the composition of the xylem exudate in two pot experiments, one conducted at ICRISAT (Table 7) and the other at the University of the West Indies (Fig. 2). In both studies, the amount of ureides in the xylem exudate decreased as nitrogen in the growth medium increased; at 75 ppm N and above in the determinate cv UWI-17 (data not presented), nodulation was minimal and the level of ureide was very low. At ICRISAT, using cv ICP-1 with no added nitrate, we found ureide accounted for 54% of the total soluble Kjeldahl N at 80 days after planting; with 100 ppm N, the ureide level was reduced to 16%. Nitrogenase activity and nodule production followed a similar trend. In the study with cv UWI-17 (Fig. 2) the level of nitrate present in the xylem exudate increased with increasing N level in the growth medium, but the concentration remained relatively constant with time. The concentration of amides and amino acids in the xylem exudate increased with increasing nitrate level in the growth medium, and there was a pronounced increase after the peak activity of

Table 7. **Effect of nitrate on nodulation, nitrogenase activity, and reduced nitrogen compounds in the xylem sap of 80-day pigeonpea.**[a]

Nitrate-N (ppm)	Nodule no./plant	Nodule wt./plant (mg)	Nitrogenase activity μmol C_2H_4/plant/hr	Allantoin in xylem sap μgN/plant/hr	Allantoin as % total soluble Kjeldahl-N	Amino-acids + amides in xylem sap *μg* N/plant/hr
0	104	203	5.3	312	54	88
25	111	256	6.5	265	50	98
50	57	117	2.8	215	42	101
75	63	64	1.9	80	16	55
100	62	65	1.2	74	16	59

a. Pigeonpea cultivar ICP-1 was grown in sand culture and watered daily to excess with nutrient solution containing nitrate at the levels indicated.

the nodules when the concentration of ureide was declining.

In another field experiment at ICRISAT, five pigeonpea cultivars were grown in an Alfisol and the allantoin and amino acid + amide nitrogen determined. The allantoin flux from roots increased up to the last harvest at 90 days (Table 8) and followed reasonably well the nitrogenase

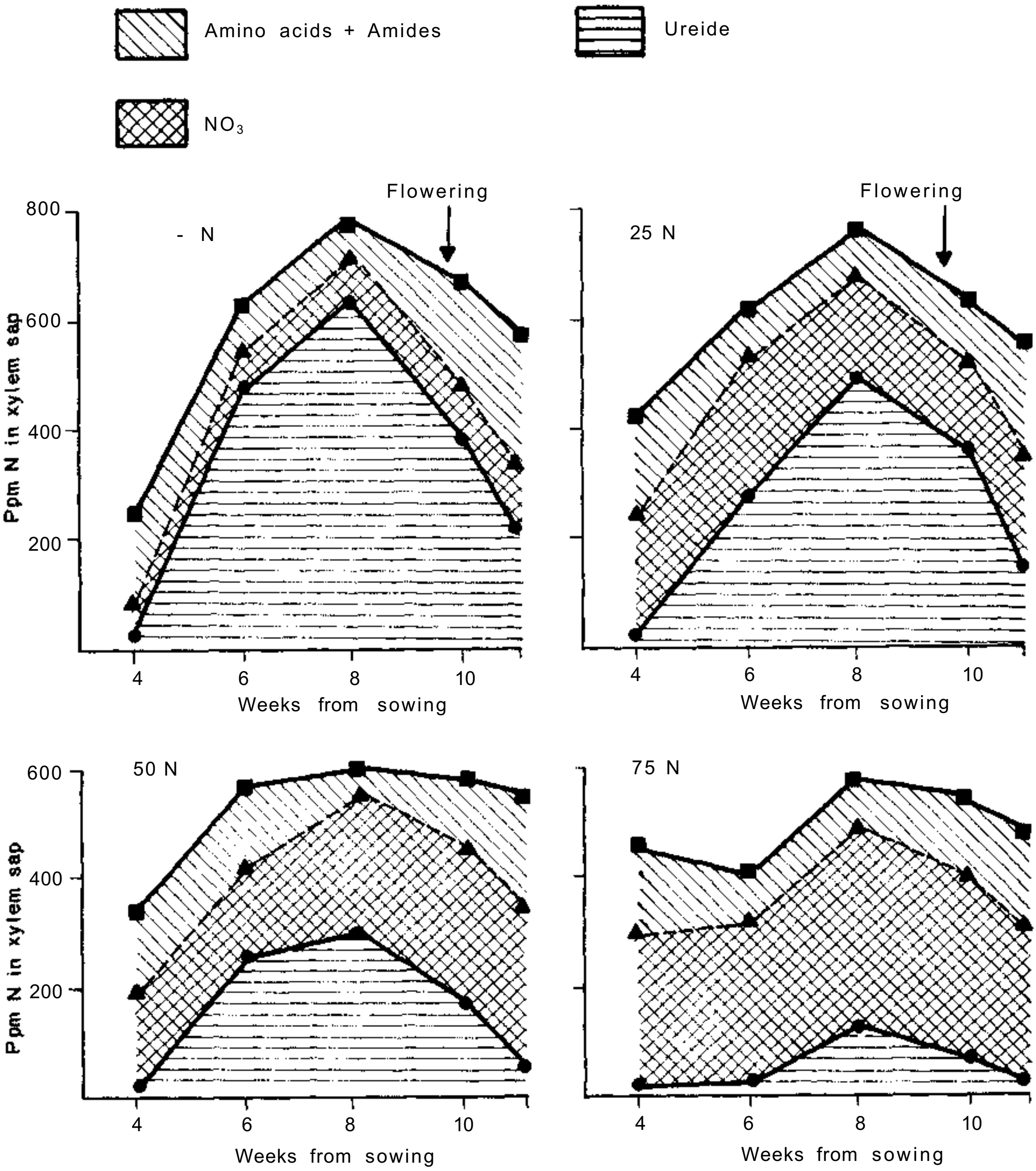

Figure 2. Concentration of ureide (allantoin and allantoic acid), amino acids plus amides (A + A) and nitrate in the bleeding sap of pigeonpea cv UWI-17 grown with nutrient solutions containing 0, 25, 50 and 75 ppm NO_3-N.

Table 8. Seasonal profile of allantoin and amino-N (μg N/plant/hr) in xylem sap of pigeonpea grown on Alfisol, rainy season 1979.

Cultivar	40 days All-N	40 days Am-N	50 days All-N	50 days Am-N	60 days All-N	60 days Am-N	70 days All-N	70 days Am-N	80 days All-N	80 days Am-N
ICP-1	26 (45)	14	31 (57)	21	109 (45)	58	367 (49)	102	157 (61)	48
T-21	39 (54)	17	48 (39)	31	144 (38)	71	184 (58)	49	445[a] (47)	144[8]
C-11	49 (46)	24	80 (49)	47	239 (46)	105	174 (39)	61	633 (49)	172
ICP-7035	20 (17)	7	69 (52)	38	204 (42)	121	215 (54)	59	526 (59)	94
MS-4 x C-11	37 (45)	17	90 (45)	49	192 (54)	103	138 (57)	31	797[a] (49)	246

Values in parentheses are allantoin-N as percentage of total soluble Kjeldahl-N.
All-N = Allantoin-N; Am-N = Amino-N.
a. Xylem sap not avilable at 80 days so collected at 90 days.

Table 9. Concentration (μ g N/g dry wt) of allantoin, amino acids and amides (AA) in parts of pigeon pea cv ICP-1 at 100 days.

Plant Part		Approximate distance from tip of stem or branch (cm) 0-20	20-40	40-60	60-80	80-90	90-100	100-110	110-120
Main stem	Allantoin	1195	239	130	117	106	119	147	175
	AA	1485	788	467	353	340	359	421	405
Branches	Allantoin	1284	413	182	186	142	127		
	AA	1709	851	607	534	394			

Plant part					
Leaves	Allantoin	167	Nodules	Allantoin	709
	AA	556		AA	3332
Primary roots	Allantoin	114	Flowers	Allantoin	1243
	AA	417		AA	1248
Secondary roots	Allantoin	132	Young pods	Allantoin	1545
	AA	538		AA	1870

activity (Fig. 3). Allantoin was the major nitrogenous compound in the sap. There appear to be differences between cultivars in the amount of allantoin and amino acid + amide nitrogen in the sap.

Allantoin concentration was measured in different parts of the pigeonpea plant at 100 days after sowing. In stem and branches, the highest concentration was found in the top 20 cm and then decreased in the older parts (Table 9). This suggests that the concentration in shoot tips may provide a sensitive measure of nitrogen-fixing activity. Levels were also high in flowers and young pods.

The data presented for pigeonpea show that a close relationship exists between the ureide content, particularly of the xylem exudate, and the nodulation status of the plant However, there is always an appreciable amount of amide and amino acid N present in the xylem exudate,

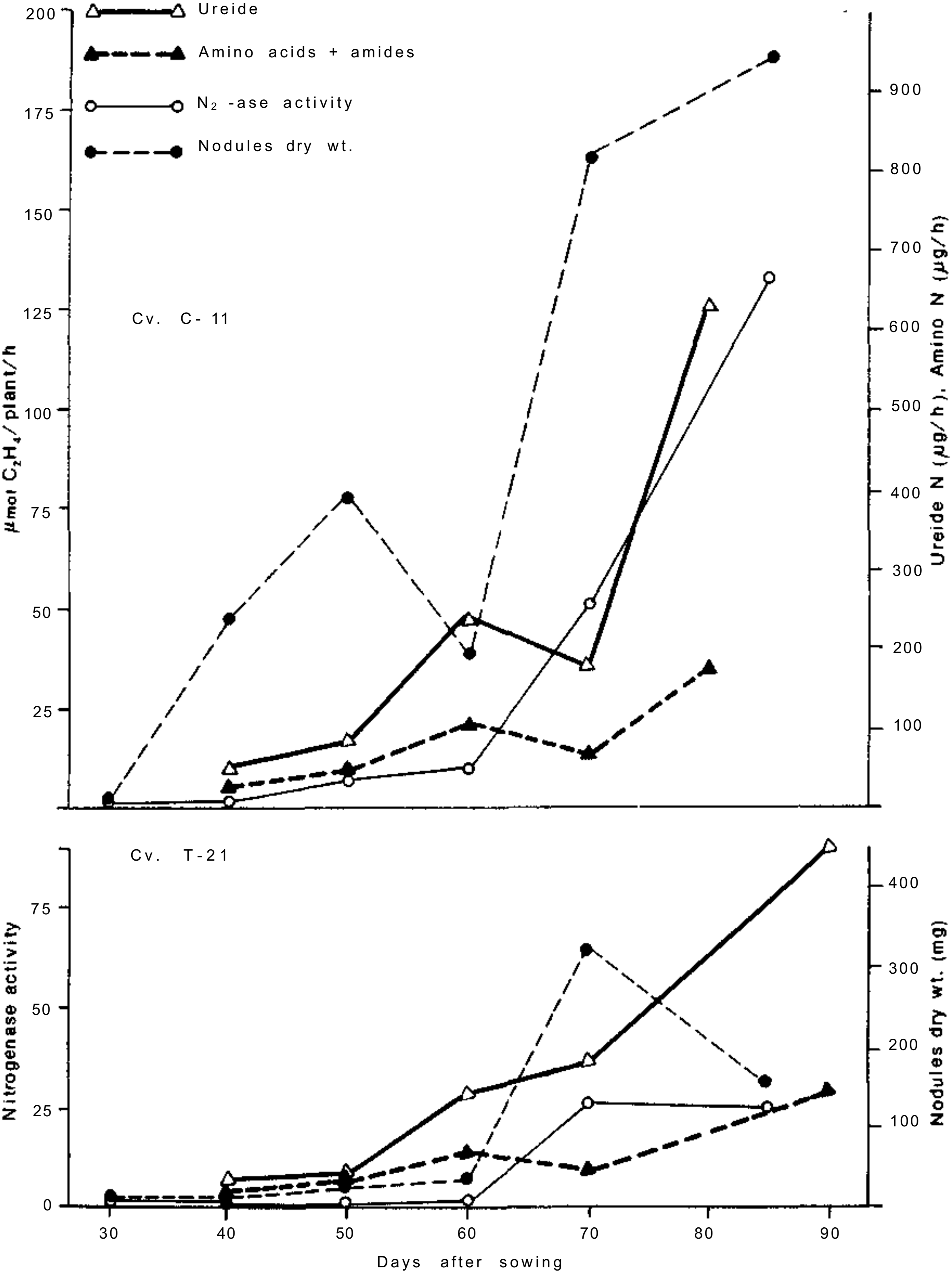

***Figure 3.** Variation in ureide (allantoin and allantoic acid), amino acids + amides, nitrogenase activity and nodules dry weight per plant of pigeonpea cultivars.*

and it is the source of this nitrogen that determines the usefulness of xylem exudate analysis as a measure of nitrogen fixation. The amide and amino N could come either from fixation or via nitrate reductase activity in the roots. If nitrate is not reduced in the roots to any significant degree, then the total reduced nitrogen, i.e., ureide plus amino acid and amide N, would be derived from nitrogen fixation and the amount of nitrate the uptake from soil nitrogen. If, however, appreciable nitrate reductase activity occurs in the roots of pigeonpea, the relationship will be less reliable. Before the value of this technique can be assessed, it is necessary to determine the nitrate-reductase status of pigeonpea roots over a range of nitrogen nutrition using ^{15}N-labeled N03 and assaying the xylem exudate for the presence of ^{15}N-labeled amino acids.

In conclusion, although pigeonpea produces a large biomass, nitrogen fixation apparently contributes a relatively small amount to its total nitrogen uptake compared with other grain legumes; however, it is very difficultto measure nitrogen fixation, and this may well be an underestimate. Pigeonpea has a large residual effect on subsequent crops, and this should enhance its claims to be part of a rotation with cereals in SAT agriculture. We are hopeful that allantoin might be a useful indicator of nitrogen fixation; we will then have a means of measuring nitrogen fixation throughout the life cycle.

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References

HARDY, R. W. F., HOLSTEN, R. D., JACKSON, E. K., and BURNS, R. C. 1968. The acetylene-ethylene assay for N2 fixation: laboratory and field evaluation. Plant Physiology 43:1185-1207.

HARDY, R. W. F., and HOLSTEN, R. D. 1977. Methods for measurement of dinitrogen fixation. Pages 451-485 *in* A treatise on dinitrogen fixation. Section IV, eds. R. W. F. Hardy and A. H. Gibson. New York: John Wiley.

MATSUMOTO, T., YAMAMOTO, Y., and YATAZAWA, M. 1975. Role of root nodules in the nitrogen nutrition of soybeans. 1. Fluctuation of allantoin and some other plant constituents in the growing period. Journal of the Science of Soil and Manure (Japan) 46: 471-477.

MATSUMOTO, T. YAMAMOTO, Y., and YATAZAWA, M. 1976. Role of root nodules in the nitrogen nutrition of soybeans. 2. Fluctuation in allantoin concentration of the bleeding sap. Journal of the Science of Soil and Manure (Japan) 47: 463-469.

QUILT, P.,and DALAL, R. C. 1979. Effect of soil mineral N levels and inoculation on nodulation, nitrogenase activity and grain yield of pigeonpea. Agronomy Journal 71: 450-452.

SHELDRAKE, A. R., and NARAYANAN, A. 1979. Growth, development and nutrient uptake in pigeonpeas (*Cajanus cajan*). Journal of Agricultural Science (Cambridge) 92: 513-526.

Discussion — Session 5

D. Sharma:

Can you define what you mean by working on a trial-and-error basis? Is it possible to predict crop phenology for specific agro-climatic and farming systems from laboratory studies done at one or two locations? If a large number of locations is required, would it not be more practical to study the crop in a specific situation and try to draw our rationale from farmers' wisdom, which has resulted in establishing those systems in their environment?

Lawn:

My comments on "trial-and-error" research were directed primarily at physiologists who do not take G x E interaction into account in their work. With respect to prediction of phenology, crude estimates of relative maturity can be made from serial sowing date studies at one or two sites, but these may not enable assessment of complex temperature x daylength interactions. In my paper, I have made a reference to the useful complementary role of controlled environment and field work in phenology prediction.

N. G. P. Rao:

A statement was made that genetic approaches based on phenotypic criteria are inadequate to predict performance levels and environment responses. To date, enzyme criteria, screening for photosynthetic efficiency, etc., have not been used as selection criteria by the breeders. Could we have further comments on more efficient criteria?

Lawn:

The thrust of my paper is that a sound knowledge of ecophysiology can make for more efficient prediction of G x E interaction. I am not surprised that selection for enzymatic levels and photosynthetic efficiency were not successful. In the first case, no relationship between enzyme level and yield was ever established; in the second, selection for absence of photorespiration in C_3 plants failed. In the case of photosynthetic rate of individual leaves, Dr. Rawson in this session has clearly illustrated the problems inherent in a screening program.

D. Gangadhara Rao:

How far are you justified in using the terms competitive and noncompetitive spacing in your experiment, when there is a mixed response in terms of yield and dry matter of the five genotypes and two population levels?

D. N. Singh:

Plant responses to a given spacing depend primarily on genetic make-up; thus we expect to have differential trends with cultivars of different genetic background.

Lal:

T-7 is an erect and compact type, not spreading, as mentioned by you. Also the number of leaves in pigeonpea represents the number of nodes. Therefore, how can the number of nodes be more than the number of leaves per mother shoot as represented in the graphs?

D. N. Singh:

Information on the growth habit of T-7 was based on the observation recorded in the experiment and is given as such. At the initial stage of crop growth, node number tallies with the existing green leaf number. At later stages, lower leaves fall off, resulting in a difference between the number of green leaves and node number on the mother shoot.

Katiyar:

1. What was plant-to-plant spacing in the

two populations in order to obtain desired plant population?

2. Why was N not applied in the experiment, when P_2O_5 and K were applied? Application of N is part of the recommended package of practices.
3. It would have been better if the results had been discussed taking into consideration complete statistical analysis of data and meteorological observations for the 2 years.

D. N. Singh:

1. In wider rows the plants were spaced 50 cm apart and in closer rows, 20 cm apart.
2. Since the crop did not show response to N application in deep alluvial sandy loam soil, only P_2O_5 and K_2O were added.
3. Most of the data were subjected to statistical analysis except in a few cases.

Wallis:

Could you comment on the extremely high seed yields of up to 6150 kg/ha recorded in this trial?

D. N. Singh:

High yields are possible if the plant populations are kept at a high level. Further, late-maturing cultivars have sufficient time to utilize the available moisture and nutrients from the soil and these would lead to increased filled grain percentage.

Patil:

It wou ld be worthwhile to study the relation between development of active nitrogen-fixing tissue and leaf age and photosynthetic rate. Dr. Kumar Rao's paper indicated active fixation at 85 days but Dr. Rawson's paper showed maximum photosynthetic rate in 20-day-old leaves.

Rawson:

There is no conflict in the data. The photosynthesis data were based on the age of inidividual leaves, whereas the nitrogenase data were based on the plant age. At 85 days, plants would have reached close to maximal green leaf area, therefore activity *per plant* wou ld have been at a peak. I agree that there is work to be done on nitrogen and carbon relations of leaves and plants.

Whiteman:

What is the contribution of the pod to the photosynthetic input for pod filling?

Rawson:

We have made no measurements in pigeonpea, but data on soybean indicate that 20 to 40% of the respiratory requirements can be met by the photosynthesis of sunlit pods. In determinate pigeonpea, where the pods are at the top of the canopy, we might expect the contribution from pod photosynthesis to exceed that in indeterminate types.

Tahiliani:

What are the causes of leaf drop and flower drop?

Rawson:

Leaf drop occurs when the photosynthetic activity of the leaf is not sufficient to balance its respiration or when nitrogen and other elements are withdrawn into other plant parts. With regard to flowers, the hypothesis we have presented suggests that there is a peak of respiration on the day of flowering, which, in limiting conditions such as cloudy weather, water stress, or the presence of pods in close proximity to the flowers, cannot be matched by photosynthesis of leaves close to the flower. In this event an abscission layer is commenced.

Balasubramanian:

Since the rhizosphere volume for extraction of soil nitrogen will not be the same for sorghum and pigeonpea, are you justified in using nitrogen uptake by sorghum to compare and reduce the nitrogen fixed by pigeonpea? I think the proper comparison can be made only with nonnodulating isogenic pigeonpea genotypes.

J. V. D. K. Kumar Rao:

I fully agree with you. But since we do not have a nonnodulating isogenic pigeonpea for proper comparison, we used sorghum (a long-duration cultivar) to measure available soil nitrogen. The assumptions and limitations of this method are given in the paper. We hope the estimation of ^{15}N might give us correct information on nitrogen fixation by pigeonpea under field conditions.

Session 6

Plant Nutrition

Chairman: D. G. Edwards   Rapporteurs: I. M. Rao
J. V. D. K. Kumar Rao

Development of Research on Pigeonpea Nutrition

D. G. Edwards*

Abstract

This paper examines principles on which future research on the nutrition of pigeonpea should be based. The general observation that pigeonpea responds poorly or not at all to fertilizer application raises questions concerning the reasons for such results. In some cases it may simply be that the soil is well-endowed with those elements essential for adequate nodulation and maximal plant growth. In other cases, one or more of the elements essential for nodulation and growth may be at an inadequate level of supply, thereby preventing or minimizing a yield response to the element under test.

Sound development of future research on nutrition of pigeonpea demands the supply of all essential elements, other than those directly under study, as a basal fertilizer at rates that do not limit growth, nodulation, or nodule function. Plant analysis and soil testing both have an important role to play in the calibration of plant response and, ultimately, in the identification of nutritional limitations on pigeonpea growth and grain yield in farmers' fields.

Comparatively little detailed research on the nutrition of pigeonpea appears to have been conducted until now (El Baradi 1978). In this paper, I do not intend to review the published and comparatively modest literature on nutrition of pigeonpea in any detail, but rather to focus on some of the principles on which development of research on pigeonpea nutrition should be based.

A view has been expressed on more than one occasion that grain legumes grown in the tropics do not respond to fertilizers. In pigeonpea, grain yield responses to fertilizer application have been described as erratic (Dalai 1980) and difficult to obtain (Rachie and Roberts 1974). In seeking explanations for the failure of grain legumes in the tropics to respond to fertilizers, it must be borne in mind that legumes can only fix sufficient nitrogen for maximal growth when they are adequately supplied with all essential elements, including micronutrients, and that they only fix nitrogen when nodulated with appropriate strains of *Rhizobium* (Hallsworth 1972). The requirements for calcium, molybdenum, cobalt, and copper for nodulation and nodule function are greater than for the growth of the host plant itself. Thus, a shortage in supply of any one of these elements will limit the response to applications of phosphorus or potassium, particularly in the absence of inorganic nitrogen. Since inorganic nitrogen levels in many tropical soils are low, legumes that are poorly nodulated or not nodulated at all will show little response to applications of phosphorus or potassium. These principles must be taken into account in designing fertilizer experiments with pigeonpea.

Symptoms of Nutritional Disorders

Visual symptoms of nutrient deficiencies and toxicities often play an important role in the diagnosis of nutrient disorders of field-grown plants. However, this approach is not infallible, because different disorders may produce similar visual symptoms, in which case confirmation of the diagnosis is dependent on plant analysis. Substantial yield reductions may

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occur without any accompanying visual symptoms and once again plant or soil analysis may be necessary to correctly diagnose the limiting nutrient.

Nonrenewed or intermittently renewed water cultures and sand cultures have been widely used to produce symptoms of nutritional disorders by modifying the initial composition of the nutrient solution (Asher and Edwards 1981). Descriptions of the symptoms of deficiency of most essential elements and of the most common nutrient toxicities intemperate agricultural species have greatly aided the diagnosis of nutritional problems under both greenhouse and field conditions. Such descriptions are not widely available for most tropical agricultural species, with the exception of rice (Tanaka and Yoshida 1970) and cassava (Asher et al. 1980).

Information available on nutrient deficiency symptoms of pigeoppea is restricted to the elements nitrogen, phosphorus, potassium, calcium, magnesium, and iron (Nichols 1964). In this study, which utilized sand culture, an attempt to develop sulfur deficiency symptoms was unsuccessful. In studies utilizing nonrenewed solution cultures at the University of Queensland, additional nutritional disorders that have been described include sulfur, manganese, boron, and zinc deficiencies and manganese toxicity (Edwards and Asher, unpublished). Solution cultures offer greater versatility than sand cultures in the development of nutrient deficiencies, because the problem of removing contaminant micronutrients from sand is avoided.

The technology necessary to produce symptoms of the deficiencies of most of the essential nutrient elements in pigeonpea is readily available. In fact, there is no logical reason why such information cannot ultimately be compiled in a publication similar to that recently released on cassava (Asher et al. 1980).

Internal Nutrient Requirements

Diagnosis of nutrient deficiencies from plant analysis is based on the existence of a predictable functional relationship between nutrient concentration within the plant or some selected index tissue and yield (Bates 1971). The critical concentration for deficiency is often taken as the concentration within the tissue corresponding to 90% of maximum yield.

No critical concentration data for any of the essential elements are available for pigeonpea. No reports have been made on systematic experiments on rate of element response, in which a yield response to the element under study was obtained and in which the concentration of that element in the plant or some index tissue was determined. Dalai (1974) obtained a significant grain-yield response by pigeonpea cv GI 27/4A to 20 kg N/ha, but did not determine nitrogen concentrations in the plant. In a subsequent field experiment on the same soil, Dalai and Quilt (1977) reported increases in nitrogen concentration of the tops of cv GI 27/4A sampled at 6 weeks from 3.36 to 3.77% as the nitrogen fertilizer rate was increased from 0 to 30 kg/ha. However, no responses in grain yield to nitrogen application were obtained in that experiment. Dalai and Quilt (1977) also investigated the grain-yield response to four rates of phosphorus and four rates of lime; they obtained no yield responses and did not provide any information on phosphorus and calcium concentrations in their plants.

The most comprehensive compilation of nutrient concentrations in deficient and well-grown pigeonpea plants arises from the sand culture experiment of Nichols (1965). Concentrations of six elements in leaves were determined at 9 and 16 weeks after planting (Table 1). Although these data are useful in that they

Table 1. Concentrations of six elements in leaves of pigeonpea cv 02/58 grown in sand culture irrigated with either a complete nutrient solution or a solution deficient in the element under study.

	Concentration (%) in dry matter at			
	9 weeks		16 weeks	
Element	Deficient	Adequate	Deficient	Adequate
Nitrogen	1.3	3.2	2.0	3.3
Phosphorus	0.05	0.38	0.06	0.22
Potassium	0.34	2.60	1.37	1.95
Calcium	0.69	2.00	0.50	1.19
Magnesium	0.06	0.23	0.15	0.42
Iron	0.027	0.028	0.017	0.016

Source: Nichols 1965.

provide some information on concentrations to be expected in leaves of deficient and healthy plants, they are not as valuable as critical concentrations, which probably fall somewhere between the values indicative of deficiency and adequacy in Table 1. A further problem with the approach used by Nichols (1965) is that the leaf samples analyzed comprised leaves of widely differing physiological age (Bates 1971).

Since critical nutrient concentrations can vary with many plant and environmental factors, it has been strongly recommended that the plant tissue sampled should be as closely standardized as possible (Chapman 1964; Bates 1971). Commonly, theyoungest fully expanded leaf or a composite of two or three recently matured leaves is used as the sampling unit so that tissue sampled approaches a uniform physiological age. Thus, for soybeans, Jones et al. (1971) recommended sampling two or three fully developed leaves at the top of the plant, while Asher et al. (1980) recommended using the youngest fully expanded leaf for cassava. Following a comprehensive study, Lee et al. (1981) concluded that the third leaf from the top of the plant was the most practical index tissue for determining the nitrogen status of field-grown ginger. Lee et al. (1981) also showed that the critical nitrogen concentration in ginger leaves declined linearly with time even when tissue of similar physiological age was selected as the sampling unit on the different sampling occasions. In many agricultural crops this problem is avoided by sampling only once at a clearly recognizable stage of plant growth, e.g., commencement of flowering. Such an approach is clearly practicable with pigeonpea. However, the wide variation in time from planting to commencement of flowering among pigeonpea cultivars and across planting dates with a given cultivar could have a substantial effect on critical nutrient concentrations. Studies are clearly required in this area.

It has been widely assumed that the critical nutrient concentration is a relatively stable plant characteristic unlikely to be affected by temporal variation in external supply of the nutrient under study. Recently, Spear et al. (1978) have shown that critical potassium concentrations in a range of index tissues of cassava depend on the volume of nutrient solution in which plants were grown. This result calls into question the validity of applying critical nutrient concentrations established in small volume solution culture experiments to field-grown plants. The more general problem concerning the application of critical nutrient concentrations determined in greenhouse experiments to field-grown plants is the subject of some difference of opinion (Bates 1971). In some instances, greenhouse-derived critical concentrations have been applied to field-grown plants with considerable success.

Solution and soil-culture experiments conducted under greenhouse conditions have limitations, but their value in establishing critical nutrient concentrations in pigeonpea should not be ignored. The ultimate value of such critical nutrient concentrations can only be assessed after their applicability to field-grown pigeonpea crops has been evaluated in simple rate-of-nutrient-response experiments conducted in the field.

External Nutrient Requirements

Soil tests are largely empirical procedures used in determining the nutrient status of soils and in predicting fertilizer requirements. A successful soil-test procedure must extract all or a proportionate part of the plant-available nutrient from a wide range of soils through rapid and accurate techniques. In addition, the amount of nutrient extracted should be calibrated with crop response when other nutrients or conditions are not limiting (Cox and Kamprath 1972, Sanchez 1976).

The search for and development of new soil test procedures is a continuing endeavor, despite their widespread and successful use in soil fertility evaluation and the establishment of fertilizer rates for optimal crop production in developed countries. The history of use of soil tests in the tropical and subtropical countries in which pigeonpea is grown is much more recent.

Sanchez (1976) has proposed the idea that the interpretation of rate-response trials conducted in the field is the basis on which fertilizer recommendations should be made and that optimum rates should be determined for specific soil-crop categories. Accepting this proposition, we can see a need for the development of a sound body of soil-test information and fertilizer recommendations specifically for pigeonpea.

Very little use has been made of soil testing in fertilizer experiments with pigeonpea. Even where it has been used, the purpose has been simply to characterize the nutrient status of the experimental site and not to calibrate dry-matter production or grain yield against soil-test values. Accordingly, the published data are very sporadic and insufficient to allow any general inferences to be drawn. Manjhi et al. (1973) reported positive and significant grain-yield responses of pigeonpea to applied nitrogen (25 kg N/ha), potassium (20.8 kg K/ha), and phosphorus (21.8 and 43.7 kg P/ha) in a trial conducted at the Indian Agricultural Research Insitute (IARI) Delhi on a soil containing 0.054% total nitrogen, 0.19 meq./100 g exchangeable potassium and 3.4 μ g/g available phosphorus. Dalai (1974) reported a grain yield response by cultivar GI 27/4A to 20 kg N/ha when grown on an Inceptisol with a total nitrogen content of 0.147%, while Dalai and Quilt (1977) failed to obtain a yield response to nitrogen or phosphorus on the same soil when the total nitrogen content was 0.14% and available phosphorus (extracted with 0.001M H_2SO_4 at pH 3) was 10 μ g/g. Evans and Mitchell (1962) reported that grain yield of pigeonpea was increased from 403 to 1180 kg/ha two years after 66 kg K/ha was applied to a Tanganyikan soil with 0.10 meq./100 g exchangeable potassium.

The recorded grain yield responses of pigeonpea to fertilizer application have ranged from zero in several studies to the 114% yield increase from 1290 to 2760 kg/ha achieved by Chowdhury and Bhatia (1971) with the application of 44 kg P/ha as superphosphate. Several reasons can be advanced for the failure to obtain responses, but in general, insufficient information is provided for such a resolution to be achieved. Trials have largely considered nitrogen, phosphorus, and potassium and have almost totally ignored the micronutrient requirements of nodulated pigeonpea; they have not used basal fertilizers to ensure that the only limiting element is the one under test; they have not used soil-test parameters as a basis for establishing treatments and calibrating responses; and often, they have failed to assess or provide any information on nodulation. The only published studies on pigeonpea that have even considered the possibility of micronutrient responses are those of Dalai and Quilt (1977) and Dalai (1980). The former study failed to obtain any yield response to 250 g Mo/ha, while in the latter study grain yield was increased from about 2060 to 2580 kg/ha over an unfertilized control by two compound fertilizers (N, P, K, and Zn; N, P, K, Zn, B, Cu, Mn, and Mo). This experiment is unsatisfactory in that it does not allow the growth-limiting element(s) to be identified, but at least it has the virtue of eliminating boron, copper, manganese, and molybdenum from the list of potential growth-limiting elements.

A clear need exists for systematic rate-response experiments to be conducted under both greenhouse and field conditions with soils that are used for pigeonpea production. These calibration experiments need to be carried out with both macronutrient and micronutrient elements and must ensure that all elements other than those under test are adequately supplied and that plants are well-nodulated with an effective strain of *Rhizobium.* Once critical soil-test values are determined from such experiments, it should be possible to categorize soils for pigeonpea production into responsive and nonresponsive and to predict the fertilizer requirements for optimum biological or economic yield. Limitations do exist in many of the currently used soil tests, but this should not prevent progress from being made by selection from those available. Sanchez (1976) should be consulted for information on soil tests for use on tropical soils. It should also be borne in mind that a need exists for the development and use of soil tests particularly for the exchangeable cations which take into account the large variable charge component of many tropical soils (Bell and Gillman 1978).

Tolerance of Pigeonpea to Adverse Soil Factors

Pigeonpea is cultivated over a wide range of tropical climates from very humid to semi-arid (Rachie and Roberts 1974). Across this climatic range it is grown on a wide range of soils varying in pH from highly acid to alkaline. At the extremities of the pH range it may encounter various adverse soil factors with the potential to limit its growth.

Dalai and Quilt (1977) obtained no significant grain-yield response when cultivar GI 27/4A was

Table 2. Effect of lima on soil pH, dry-matter yield, nodule weight, and rata of nitrogen fixation as measured by acetylene reduction assay of pigeonpea cv Gl 27/4A grown for 6 weeks in an Inceptisol at St. Augustine, Trinidad.

Lime rate (t/ha)	Soil pH (H_2O)	DM yield (kg/ha)	Nodule wt (g/ha)	Rate of nitrogen fixation n moles C_2H_2 reduced (g/plant/hr)
0	4.8	125	461	119
1.25	5.2	139	493	60
2.5	5.6	120	413	63
5.0	5.9	133	227	67
LSD (0.05)	0.36	19	221	80

Source: Dalai and Quilt 1977.

grown on an Inceptisol of pH (H2O) 5.2 at lime rates from 0 to 5.0 t/ha. The highest lime rate increased soil pH to 5.9. This study is significant in that nodule weights and rates of nitrogen fixation were determined at 6 weeks after planting (Table 2). Nodule weight was significantly reduced at the highest lime rate; although nitrogen fixation rates at all lime rates were similar and only about one-half of the rates determined in the absence of lime, these differences were not significant. In studies of the tolerance of a number of tropical grain legumes to high soil acidity conducted at IITA, Edwards and Kang (unpublished) obtained strong responses in vegetative growth and in nodulation of pigeonpea cultivar 3D8103G to the application of lime when grown on a highly acid Ultisol (Table 3). Although the seed was inoculated with the appropriate "Nitragin" inoculant, complete nodulation failure occurred in the unlimed soil. Maximum yield and nodulation were achieved at pH 5.2 and strong depressions in both yield and nodulation occurred at the highest lime rates. The low calcium concentration (0.17% Ca) in the whole tops of pigeonpea grown in the unlimed soil (cf. Table 1) and the symptoms observed — which were similar to those previously reported for calcium deficiency (Nichols 1964) — suggest that pigeonpea growth was primarily limited by calcium deficiency. Total nodulation failure on the unlimed soil is consistent with reports for other legumes that calcium requirements for nodulation are greater than those for host-plant growth (Loneragan and Dowling 1958; Lowther and Loneragan 1968). Both the symptoms developed and chemical analysis of tops grown at the highest lime rate (5.0 t/ha) indicated and yield depression was due to lime-induced zinc deficiency.

The above liming experiments demonstrate that pigeonpea can nodulate and grow well on acid soils. Furthermore, the study of Edwards and Kang (unpublished) demonstrates that relatively low rates of lime application are adequate for good growth and can considerably extend the range of acid soils on which pigeonpea can be grown. However, the high costs of lime in many tropical countries may well preclude its

Table 3. Effect of lime on soil pH, relative dry-matter yield of tope, and relative dry-matteryleM of nodules of pigeonpea cv 3D-8103G grown for 45 days In an Uitisol from southeastern Nigeria.

Lime rate (t/ha)	Soil pH (H_2O)	Relative yield of tops (%)	Relative yield of nodules (%)
0	4.30	31.0	0.0
0.25	4.48	46.1	0.9
0.5	4.60	70.1	52.0
1.0	4 88	85.5	95.5
1.6	5.21	100.0	100.0
2.5	5.68	96.2	89.1
3.75	6.30	78.3	20.4
5.0	7.03	44.8	0.3

Source: Edwards and Kang unpublished.

use on pigeonpea. In this event, cultivars that possess maximal tolerance to high soil acidity should be selected and used. As yet, no such studies on cultivar tolerance to high soil acidity appear to have been conducted.

Successful production of pigeonpea on highly acid soils demands an understanding of the ability of the plant to cope with the various adverse factors that commonly occur in such soils. Considerable danger exists in extrapolating from the behavior of other plant species, even other legumes, in predicting the ability of pigeonpea to grow in a particular acid soil. Different factors may limit the growth of different legumes when grown in the same acid soil (Edwards and Kang, unpublished). The ability of a pigeonpea cultivar to grow well in an acid soil does not necessarily mean it will grow well in all acid soils of similar pH. In any given soil, the adverse factor limiting growth of pigeonpea should be identified and the appropriate strategy to remove or overcome such a limitation should be devised. At all times, recognition should be given to the fact that pigeonpea is grown in symbiotic association with *Rhizobium.*

The two major nutritional problems that may limit growth of pigeonpea on alkaline soils are low micronutrient availability and salinity. Growth reduction caused by lime-induced zinc deficiency has been discussed above. Salinity tolerance does exist among pigeonpea cultivars; most of the 23 cultivars studied by Paliwal and Maliwal (1973) tolerated a salinity level of 6 to 12 mmhos/cm. Grain yields as high as 982 kg/ha have been reported on black cotton soils of pH 8.0 to 8.5 at Indore (Singh and Sahasrabudhe 1957), suggesting that some tolerance may exist to the problems of low micronutrient availability in such soils.

References

ASHER, C. J., and EDWARDS, D. G. 1980. Modern solution culture techniques. *In* Encyclopaedia of plant physiology, new series. Vol. 12. Inorganic Plant Nutrition (eds. A. Lauchli and Ft. L. Bieleski). (In press.)

ASHER, C. J., EDWARDS, 0. G., and HOWELER, R. H. 1980. Nutritional disorders of cassava. Department of Agriculture, University of Queensland, St. Lucia, Australia.

BATES, T. E. 1971. Factors affecting critical nutrient concentrations: a review. Soil Science 112: 116-130.

BELL, L. C, and GILLMAN, G. P. 1978. Surface charge characteristics and soil solution composition of highly weathered soils. Pages 37-57 in Mineral nutrition of legumes in tropical and subtropical soils (eds. C. S. Andrew and E. J. Kamprath). Melbourne, Australia: CSIRO.

CHAPMAN, H. D. 1964. Foliar sampling for determining the nutrient status of crops. World Crops 16: 35-46.

CHOWDHURY, S. L.and BHATIA, P. C. 1971. Profits triple when arhar is adequately fertilized. Indian Farming 20: 27-30.

Cox, F. R., and KAMPRATH, E. J. 1972. Micronutrient soil tests. Pages 289-317 *in* Micronutrients in agriculture (eds. J. J. Mortvedt, P. M. Giordano, and W. L. Lindsay). Madison, Wis, USA: Soil Science Society of America.

DALAL, R. C. 1974. Effects of intercropping maize with pigeonpea on grain yield and nutrient uptake. Experimental Agriculture 10: 219-224.

DALAL, R. C. 1980. Nutrient element concentration and dry matter production by field grown pigeonpea (*Cajanus cajan* [L.] Millsp.) Tropical Agriculture 57: 107-112.

DALAL, R. C. and QUILT, P. 1977. Effects of N, P, liming and Mo on nutrition and grain yield of pigeonpea. Agronomy Journal 69: 854-857.

EL BARADI, T. A. 1978. Pulses. 3. Pigeonpeas. Abstracts on Tropical Agriculture 4(12): 9-23.

EVANS, A. C, and MITCHELL, H. W. 1962. Soil fertility studies in Tanganyika I. Improvement to crop and grass production on a leached sandy soil in Bukoba. East African Agriculture and Forestry Journal 27: 189-196.

HALLSWORTH, E. G. 1972. Factors affecting the response of grain legumes to the application of fertilizers. Pages 1-16/n Use of isotopes for study of fertilizer utilization by legume crops, IAEA Tech. Report 149. Vienna, Austria.

JONES, J. B., JR., LARGE, R. L., PFLEIDERER, D. B., and KLOSKY, H. S. 1971. How to properly sample for a plant analysis. Crops and Soils 23: 15-18.

LEE, M. T., EDWARDS, E. G., and ASHER, C. J. 1980. Nitrogen nutrition of ginger (*Zingiberofficinale*). II. Establishment of a leaf analysis test. Field Crops Research, (In press.)

LONERAGAN, J. F., and DOWLING, E. J. 1958. The interaction of calcium and hydrogen ions in the nodulation of subterranean clover. Australian Journal of Agricultural Research 9: 464-472.

LOWTHER, W. L, and LONERAGAN, J. F. 1968. Calcium and nodulation in subterranean clover (*Trifolium subterraneum* L.). Plant Physiology 43: 1362-1366.

MANJHI, S., CHOWDHURY, S. L., and KAVITKAR, A. G. 1973. Influence of varieties, plantings rates, row spacings and fertilizer nutrients on the yield and yield components of pigeonpea (*Cajanus cajan* (L.) Millsp.). Indian Journal of Agricultural Science 43: 998-1001.

NICHOLS, R. 1964. Studies on the major-element deficiencies of the pigeonpea *(Cajanus cajan)* in sand culture. I. Foliar symptoms of the major-element deficiencies. Plant and Soil 21: 377-387.

NICHOLS, R. 1965. Studies on the major-element deficiencies of the pigeonpea *(Cajanus cajan)* in sand culture. II. The effects of major-element deficiencies on nodulation, growth and mineral composition. Plant and Soil 22: 112-126.

PALIWAL, K. V., and MALIWAL, G. L. 1973. Salt tolerance of some arhar (*Cajanus indicus*) and cowpea (*Vigna sinensis)* varieties at germination and seedling stages. Annals Arid Zone (India) 12: 135-144.

RACHIE, K. O. and ROBERTS, L. M. 1974. Grain legumes of the lowland tropics. Advances in Agronomy. 26: 1-132.

SANCHEZ, P. A. 1976. Properties and management of soils in the tropics. New York: Wiley. 618 pp.

SINGH, S., and SAHASRABUDHE, V. B. 1957. Effect of organic and inorganics on the yield of jowar *(Sorghum vulgare),* arhar (*Cajanus cajan*) and groundnut (*Arachis hypogaea*) and after effect on rainfed cotton. Indian Journal of Agronomy 1: 151-157.

SPEAR, S. N., EDWARDS, D. G., and ASHER, C. J. 1978. Effects of nutrient supply on critical nutrient concentrations in cassava plants. Pages 499-506 *in* Plant nutrition 1978. Proceedings, Eighth International Colloquium on Plant Analysis and Fertilizer Problems, Auckland, New Zealand (eds. A. R. Ferguson, R.L.Bieleski, and I.B. Ferguson). NewZealand DSIR Information Series 134, Wellington, New Zealand.

TANAKA, A., and YOSHIDA, S. 1970. Nutritional disorders of the rice plant in Asia. IRRI Technical Bulletin 10, Los Banos, Philippines.

Response of Pigeonpea to Fertilizers in India: A Critical Review

K. R. Kulkarni and K. S. Panwar*

Abstract

Of the 23.5 million hectares under pulses in India during 1977-78, pigeonpea occupied 2.6 million. Pigeonpea is mostly grown as an intercrop in cereals; at times other short-duration pulses such as mung bean and urd bean are grown as intercrops in pigeonpea. As a sole crop, it is grown only in isolated pockets. For want of short-duration, high-yielding, fertilizer-responsive varieties, the pigeonpea area under irrigation in the canal command areas is not increasing. The response of this crop to fertilizer is limited by the rainfall pattern and the available moisture in the soil profile, and varies from year to year.

A review of the literature on response of pigeonpea to nitrogen shows that a starter dose of 20 to 25 kg Nlha was beneficial in most cases, giving responses ranging from 60 to 280 kglha. Application of 40 to 60 kg P_2O_5/ha *produced responses ranging from 200 to 600kglha on cultivators' fields. Though response to potash has often been reported to be low, in soils with low available potash and in the trials on cultivators' fields, potash gave a positive response ranging from 90 to 200 kglha with 20 kg* K_2O *over 20 kg N + 40 kg* P_2O_5*. An economic analysis of trials in farmers' fields showed benefit-cost ratios ranging from Rs. 128 to Rs. 8.80 per rupee cost of fertilizer, when applied at 20 kg N, 40 kg* P_2O_5*, and 20 kg* K_2O*lha.*

The area under food crops in India increased from 97.34 million ha in 1950-51 to 126.13 million ha in 1973-74, with a corresponding increase in food production from 50.82 to 103.61 million metric tons (tonnes). Of this total increase, 51.45 mill ion tonnes was from cereals and only 1.34 million tonnes from pulses, though the area under pulses increased from 8.41 to 9.75 million ha during this period (Mamoria 1976). Out of the total area of 23.54 million ha under pulses during 1977-78, pigeonpea occupied 2.62 million ha. Out of the total pulse production of 11.80 million tonnes, the production of pigeonpea was 1.89 million tonnes. Pigeonpea is thus an important pulse crop in the country (Mukherjee 1979).

* All India Coordinated Agronomic Research Project, University of Agricultural Sciences, Bangalore; and Pulses and Oilseeds Project, Haryana Agricultural University, Bhiwani Center, India, respectively.

Except in the cooler regions, pigeonpea is grown throughout the country. As a sole crop it is grown only in isolated pockets, whereas pigeonpea as an intercrop in cereals like sorghum, pearl millet, and maize is quitecommon. It is also customary to grow different short-duration crops like mung bean, urd bean, horse gram, groundnut, etc., as an intercrop in pigeonpea. Because of lack of short-duration high-yielding fertilizer-responsive varieties, the irrigated command area under pigeonpea is not increasing. Moreover, the short-duration high-yielding cereals under adequate fertility, because of high initial vigor, do not permit pigeonpea to grow satisfactorily. The fertilizer requirement of high-yielding cereals and pigeonpea being quite different, the intercropping of pigeonpea with high-yielding cereals is becoming less practicable.

The response of pigeonpea to fertilizer is limited by the rainfall pattern and available moisture in the soil profile, and hence is variable from year to year. Pest problems are also aggravated with application of fertilizers and thereby limit the response to a certain extent. So far, the literature on response of pigeonpea to fertilizer is sparse.

Research on fertilizer use of pigeonpea has been conducted on a moderate scale under the All India Coordinated Project on pulses during the last decade. Experiments have also been conducted at the regional research stations under the provincial departments of agriculture and the research farms of agricultural universities. A good deal of work on fertilizer trials on farmers' fields has been done under the All India Coordinated Agronomic Research Project. Unfortunately, most of it has remained confined to the project reports. Very few efforts have been made to review the responses of pigeonpea to fertilizers in India (Saxena et al. 1975; Panwar 1979, 1980).

This paper reviews critically the fertilizer responses of pigeonpea both on research farms and cultivators' fields.

Pigeonpea Response to Nutrients

Nutrient uptake

A crop of pigeonpea cv Pusa Ageti yielding about 2000 kg of grain (G) and 6000 kg of sticks (S) has been reported to remove about 132 kg N (79 kg G + 53 kg S), and 46.1 kg P_2O_5 (13.4 kg G + 32.7 kg S) per hectare (Rao 1974). On an average, 115 kg N and 16 kg P/ha were removed by the pigeonpea crop grown on a sandy loam soil of the Indian Agricultural Research Institute (IARI) New Delhi (Singh et al. 1976). In sandy loam laterite soils of Bhubaneswar, Orissa, the pigeonpea crop removed 40 kg N and 8 kg P20s/ha from a crop yielding 990 kg grain and 4300 kg sticks per hectare (Lenka and Satpathy 1976).

Response to Nitrogen

Responses of pigeonpea to nitrogen were reported to be negligible or negative (Singh and Rathi 1972; USDA 1968; Panwar and Misra 1973; Panwar 1975; Singh etal. 1976). Attempts to substantiate symbiotic nitrogen fixation by applying high doses of combined nitrogen did not give positive results (USDA 1968; Saxena and Yadav 1975). However, on sandy loam soils, poor in nitrogen and organic matter, a starter dose of 20 to 25 kg N/ha has increased the yield of pigeonpea (Ram and Giri 1973; Lenka and Satpathy 1976; Roy Sharma et al. 1979). The average response to 25 kg N/ha was 260 kg/ha over control yields of 1600 and 1040 kg/ha, as reported by Manjhi et al. (1973) and Ram and Giri (1973) in the alluvial soil at IARI (Tables 1 and 2). However, at the same center, no significant response to 25 kg N was reported by Kalyan Singh and Prasad (1975) but rhizobial culture produced significant responses of 160 and 130 kg/ha over no-culture treatments, giving 2090 and 1820 kg/ha in 1970 and 1971, respectively (Table 3). In the trials on cultivators' fields (Anonymous 1973), the average response to 20 kg N/ha was 65 kg/ha over control yield of 670 kg/ha in the medium black soil of Gulbarga and mixed red and black soil of Jalaun. In the red and laterite soils of Medak, red sandy soil of Sundergarh, and mixed red and black soils of Phulbani districts, the response to 20 kg N/ha ranged from 240 to 320 kg/ha over the control yields ranging from 300 to 460 kg/ha. However, in Medak with variety Hy-3, high response of 670 kg/ha over control yield of 490 kg/ha was obtained (Table 4, 5). In the red loam soil of Dhenkanal the response to 20 kg N/ha was 60 kg/ha with variety S-5, while with UPAS-120 in the red and yellow soil of Alwar the mean response was 180 kg/ha over the respective control yields of 680 and 380 kg/ha (Table 6).

The review indicates that in many situations a starter dose of 20 to 25 kg N/ha would be essential.

Response to Phosphate

The importance of an adequate supply of phosphorous for high yields of pigeonpea has long been recognized. In one of the earliest experiments, Krauss (1932) obtained good response of pigeonpea to phosphate fertilization in Hawaii, especially in the uplands, and recommended a dose of 350 to 1000 kg of acidulated rock phosphate per hectare.

In India, responses to phosphate application have been generally positive and in some cases highly significant (Pathak 1970; Khan and Mathur 1962; Bhatawadekar et al. 1966, Ramanujam 1972; Chowdhury 1968). Inamulti-

Table 1. Effect of fertilizer levels on yield and yield attributes of pigeonpea at IARI, New Delhi, India.

Treatment	Yield (kg/ha) 1969	Yield (kg/ha) 1970	Yield (kg/ha) Average	Pods/plant 1969	Pods/plant 1970	1000-grain wt (g) 1969	1000-grain wt (g) 1970
Control	1700	1490	1600	169.5	172.5	69.5	70.0
25 kg N/ha	2000	1730	1880	183.3	185.2	72.5	73.4
25 kg N + 20.83 kg K/ha	2140	1770	1960	191.6	187.1	75.1	74.0
25 kg N +20.83 kg K + 21.53 kg P/ha	2290	1910	2100	204.1	196.1	76.5	76.0
25 kg N + 20.83 kg K + 43.67 kg P/ha	2520	2090	2300	207.9	206.4	77.5	77.0
SE ±	36	19	20	4.15	3.24	0.44	0.43
LSD (5%)	100	53	56	11.49	8.94	1.21	1.21

Source: Manjhi et al. 1973.

Table 2. Effects of fertility levels on yield, growth, and yield characters of Arhar at IARI, New Delhi, India.

Character	Control	Fertility levels (kg/ha) N P K 25 0 0	N P K 25 50 0	N P K 25 100 0	SE (±)	LSD (5%)
Branches/plant	17.9	17.3	19.4	20.8	0.85	2.44
Pods/plant	159.0	176.0	210.3	214.8	4.66	13.38
Grain/plant (g)	314.3	338.1	457.3	419.4	22.05	63.10
1000-grain weight (g)	62.53	64.16	69.63	70.77	7.89	2.54
Grain yield (kg/ha)	1041	1298	1671	1635	47	132

Source: Ram and Giri 1973.

location trial on different research farms in Uttar Pradesh, pigeonpea T-21 responded up to 40 kg P_2O_5/ha at Kanpur and Deegh (Panwar and Misra 1973; Rathi and Tripathi 1978) and up to 80 kg P20s/ha in light loam soils of Meerut (Rathi et al. 1974), but there was no response to phosphorus at Etawa (Gupta et al. 1971). At Kanpur, the date of planting had a significant effect on phosphate response of pigeonpea T-21. The crop planted at the end of June responded to P_2O_5 up to 40 kg/ha, whereas a crop planted in mid-April responded linearly up to 60 kg P_2O_5/ha(Panwarand Yadav 1978). Extra early cv Prabhat responded up to 80 kg P_2O_5/ha, whereas early (T-21) and late-maturing varieties could respond only up to 48 kg P_2O_5/ha at Kanpur (Panwar 1977).

High responses of pigeonpea up to 100 kg P_2O_5/ha application have been obtained on sandy loam soils, low in available phosphorus, at the Indian Agricultural Research Institute, New Delhi (Bains 1970; Chowdhury and Bhatia 1971; Singh et al. 1976). Manjhi et al. (1973) obtained an average response of 440 kg/ha with application of 44 kg P_2O_5/ha, as compared with the yield of 1860 kg/ha with 25 kg N/ha alone. Kalyan Singh and Prasad (1975) obtained an average response of 370 kg/ha with 50 kg P_2O_5/ha over no phosphate plots, giving 1640 kg/ha. Ram and Giri (1973) obtained a response of 370 kg/ha with 50 kg P_2O_5/ha over the yield of 1300 kg/ha with 25 kg N/ha alone. Ahlawat et al. (1975) working at IARI also obtained a response of 180 kg/ha with 10 kg N + 30 kg P_2O_5/ha over the control yield of 630 kg/ha. There was no further increase in yield with 20 kg N + 60 kg P_2O_5/ha with surface application but when half the dose was placed at 15 cm and half at 30 cm depth, the yield was increased to 980 kg/ha (Table 7). A dose of 40 kg P_2O_5/ha has been recommended for pigeonpea at New Delhi (Rao 1974; Ahlawat 1976; Hegde 1977).

At Ludhiana, Kaul and Sekhon (1975) obtained an average response of 320 kg/ha with 40 kg P_2O_5/ha over the control yield of 1550 kg/ha (Table 8). Similar results were obtained by Singh (1973) under Punjab conditions.

In Maharashtra, Khedekar (1976) reported that application of 25 kg N and 50 kg P20s/ha gave significantly higher yield than control at Kutki. Raikhelkar et al. (1976) working at Badnapur recommended a dose of 50 kg P_2O_5/ha for pigeonpea. In sandy loam laterite soils of Bhubaneswar, Orissa, the grain yield increased linearly at the rate of 128 kg per 40 kg P_2O_5 upto 120 kg P_2O_5/ha (Lenka and Satpathy 1976).

Application of 50 kg P_2O_5/ha increased the yield of pigeonpea significantly over plots with no applied phosphate at Dholi (North Bihar), whereas 100 kg P_2O_5/ha increased the yield significantly over 50 kg/ha at Pigrakothi in East Champaran (Roy Sharma et al. 1979).

In the experiments on cultivators' fields (Anonymous 1973) the response to 60 kg P2O5/ha was low, being 100 kg/ha over 20 kg N/ha alone which gave a yield of 370 kg/ha. In the medium black soil of Gulbarga, the mixed red and black soil of Jalaun, and the red sandy soil of Sundergarh, the average response to 60 kg P_2O_5/ha was 290 and 270 kg/ha over the corresponding yields of 740 and 730 kg/ha with 20 kg

Table 3. Effect of fertilizer on yield of plgeonpea at IARI, New Delhi, India.

Treatment	Grain Yield (kg/ha) 1970	1971
Level of P_2O_5 (kg/ha)		
0	1620	1670
25	2000	1820
50	2140	1890
75	2210	1960
100	2360	2090
SE±	30	30
LSD (5%)	100	80
Seeding Treatment		
No nitrogen, no culture	2090	1820
Rhizobium culture	2250	1950
25 kg N/ha	1860	1870
SE ±	30	20
LSD (5%)	80	60

Source: Kalyan Singh and Prasad 1975.

Table 4. Response (kg/ha) of pige on pea to nitrogen, phosphorus, and potaaalum fertlllzation.

Major soil group/ District	Cultivar	No. of trials	Average yield (kg/ha) Contro/	$N_{30}P_{69}$	N_0P_{40}	$N_{20}P_0$	Response over N_0P_{40} to N_{10}	N_{20}	N_{30}	Response over $N_{20}P_0$ to P_{20}	P_{40}	P_{50}	Response over $N_{20}P_{40}$ to K_{20}	LSD (5%)
Mixed red and black								1972-73						
Jalaun	T-21	11	341	484	381	367	15	33	62	34	47	100	-3	9
Medium black								1974-75						
Gulbarga	C-28	5	564	727	484	498	45	-60	168	218	-73	312	189	215
								1975-76						
Gulbarga	Local	17	1229		1322	1367	83	217	258	-18	172	242	167	98
								1976-77						
Gulbarga	Local	40	621	1121	712	671	102	158	248	129	200	372	131	31
								1977-78						
Gulbarga	GS-1	46	606		709	680	80	136	221	96	166	275	102	3
Mean		119	674		758	739	80	137	218	86	157	288	115	

Table 5. Response of pigeonpea to nitrogen, phosphorus, and potassium fertilisation.

Major soil Group/ District	Cultivar	No. of trials	Average yield of control (kg/ha)	Response to N_{10}	Response to N_{20}	Response to P20 over N_0	N_{10}	N_{20}	Response to P40 over N_0	N_{10}	N_{20}	Response to K_{20} over $N_{20}P_{40}$	LSD (5%)
						1978-79							
Red and laterite													
Medak	S-5	9	300	116	325	115	346	400	286	537	605	158	197
	HY-3	9	486	372	669	413	405	355	732	590	601	181	113
						Response to P_{30} over			Response to P_{60} over			Response to K_{20} over	
						N_0	N_{10}	N_{20}	N_0	N_{10}	N_{20}	$N_{20}P_{60}$	
Red Sandy													
Sundergarh	Local	25	457	147	277	-44	108	170	127	167	275	135	43
Mixed red and black													
Phulbani	S-4	14	292	87	237	182	261	213	314	424	511	89	41

Source: Annual progress reports of the All India Coordinated Agronomic Research Project, 1973-1979.

Table 6. Response of pigeonpea to fertilizers on cultivators' fields in crop comparison experiments; 1975—76.

Major soil group/District	Cultivar	No. of trials	Yield (kg/ha) at NoPoKo	N20P0K0	$N_{20}P_{40}K_0$	$N_{20}P_{40}K_{20}$
Red loamy						
Dhenkanal	S-5	28	679	739	1071	1208
Red and yellow						
Alwar	UPAS-120	9	382	566	733	938

Source: Annual progress report of the All India Coordinated Agronomic Research Project, 1976.

N/ha. In the red and laterite soil of Medak, high response of 600 kg/ha was obtained over the yields of 620 and 1150 kg/ha at 20 kg N/ha, with cvs S-5 and HY-3, respectively. In the mixed red and black soils of Phulbani, the mean response to 60 kg P_2O_5/ha was 510 kg/ha over the average yield of 530 kg/ha with 20 kg N/ha (Table 4, 5). In the red loam soil of Dhenkanal, the mean response to 40 kg P_2O_5/ha was 330 kg/ha over the mean yield of 740 kg/ha with 20 kg N/ha. In the red and yellow soils of Alwar the response to 40 kg P_2O_5 was 170 kg/ha over the yield of 570 kg/ha with 20 kg N/ha (Table 6).

Tne results thus indicated that the response to application of 40 to 60 kg P_2O_5/ha ranged from 300 to 600 kg/ha on farmers' fields in the majority of cases. Most of the responses are in agreement with those on the research stations, except in a few cases, as in Medak and Phulbani, where higher responses were reported.

Soil Versus Foliar Application of Phosphate

Studies on the response of pigeonpea to soil application versus foliar spray of diammonium

Table 7. Effect of fertilizers and their placement on pigeonpea at IARI, New Delhi, India.

Treatment	Yield (kg/ha)
Fertilizer dose	
Control (no fertilizer)	630
10 kg N+30 kg P_2O_5/ha	810
20 kg N+60 kg P_2O_5/ha	860
Mean fertilizer doses	840
LSD (5%) (fertilizer doses)	
LSD (5%) (fertilizer vs control)	140
Fertilizer placement	
Surface application	
20 kg N+60 kg P_2O_5 /ha	660
Placed 15 cm deep	760
Placed 30 cm deep	760
Placed half 15 cm and half 30 cm	980
LSD (5%) (placement methods)	130
LSD (5%) (surface application vs placement)	140

Source: Ahlawat et al. 1975.

Table 8. Effect of P_2O_5 levels on yield of pigeonpea at Ludhiana, India.

Levels of P_2O_5 (kg/ha)	Yield (kg/ha)	Harvest Index
0	1550	14.7
20	1640	14.9
40	1870	15.6
60	1770	15.9
LSD (5%)	130	

Source: Kaul and Sekhon 1975.

phosphate (DAP) were done under the All India Coordinated Pulse Improvement Project of ICAR during 1976 to 1978. At most of the locations (Hissar, Bangalore, Varanasi, Dholi, Badnapur, Rajendranagar.Warangal) there was no additional gain if 25 or 50 kg DAP (out of a total of 100 kg DAP) was applied by foliar spray. However, at some of these locations, foliar spray (25 or 50 kg DAP) alone was as good as 100 kg DAP through soil. But when it was compared with urea spray on an equal nitrogen basis, it seemed that the effect was due to the nitrogen component of DAP. However, at the Jabalpur and Kanpur centers, it was observed that a saving of 25 to 50 kg DAP is possible if applied as 50 kg soil+ 25 kg foliar or 25 kg soil + 20 kg foliar. Significantly higher yields of pigeonpea were obtained by applying 50 kg DAP through foliage in two sprays of 25 kg each at flower commencement and 15 days after as compared with yields obtained by applying 100 kg DAP/ha through soil at Sehore, Madhya Pradesh, and Coimbatore, Tamil Nadu (Panwar 1979).

Response to Potash

Pigeonpea normally did not respond to potassium application unless grown on soils low in available potash. Response to potassium application has been negligible (Panwar and Misra 1973; Pathak 1970; USDA 1968; Mohd. Yaseen 1979). On the fields of cultivators, however (Anonymous 1973) the responseto 20 kg K_2O/ha over 20 kg N + 40 kg P_2O_5/ha ranged from 90 to 200 kg/ha, except in Jalaun district, where response to potash was not observed (Tables 4, 5, 6). It is thus observed that as in many other crops, no response to potassium was seen at research stations, but on cultivators' fields fairly good responses were obtained.

Response to Zinc

Almost all currently available pigeonpea cultivars show a high degree of susceptibility to zinc deficiency (Saxena and Singh 1970). Soil application of 2 to 4 ppm zinc or foliar spray of 0.5% zinc sulfate with 0.25% lime have proved effective in controlling zinc deficiency.

Response to Rhizobial Inoculation

Responses to inoculation have been generally inconsistent (Panwar and Misra 1973; USDA 1968; Mohd. Yaseen 1979; Panwar 1975). At IARI, New Delhi, *Rhizobium* inoculation significantly increased the grain yield of pigeonpea, and the effects were more distinct in the presence of phosphate (Singh et al. 1976). At Dholi (Bihar) inoculation of seed with E_2 strain of IARI culture along with side dressing of *Rhizobium* culture as slurry 15 days after sow-

Table 9. Economics of fertilizer use on pigeonpea in cultivators' fields.

Major soil type/ district	Year	Cultivar	No. of expts.	Av. yield of unfertilized plot (kg/ha)	Yield (kg/ha) at fertilizer level (kg/ha) of N-P-K	Response over control (kg/ha)	Cost of fertilizer (Rs./ha)	Value of additional yield (Rs/ha)	Net profit (Rs/ha)	Benefit-cost ratio
Medium black and mixed red and black										
Jalaun	1972–73	T-21	119	674	20-0-0	65	92.00	162.50	70.50	0.77
	to	C-28			20-40-0	222	332.00	555.00	223.00	0.67
Gulbarga	1977–78	Local			20-60-0	353	452.00	882.50	430.50	0.95
		GS-1			20-40-20	337	370.00	842.50	472.50	1.28
Red and laterite										
Medak	1978–79	S-5	9	300	20-0-0	325	92.00	812.50	720.50	7.83
					20-40-0	930	332.00	2325.00	1993.00	6.00
					20-40-20	1088	370.00	2720.00	2350.00	6.35
		HY-3	9	486	20-0-0	669	92.00	1672.50	1580.50	17.17
					20-40-0	1270	332.00	3175.00	2843.00	8.56
					20-40-20	1451	370.00	3627.50	3257.50	8.80
Red sandy										
Sundergarh	1978–79	Local	25	457	20-0-0	227	92.80	692.50	600.50	6.52
					20-60-0	552	452.80	1380.00	928.00	2.05
					20-60-20	687	490.00	1717.50	1227.50	2.50
Mixed red and black										
Phulbani	1978–79	S-4	14	292	20-0-0	237	92.00	592.50	500.50	5.44
					20-60-0	748	452.00	1870.00	1418.00	3.14
					20-40-20	750	370.00	1875.00	1505.00	4.07

Cost per kg of pigeonpea Rs 2.50; nitrogen Rs 4.64; phosphorus Rs 6.00; potassium Rs 2.90.
Source: Data from All India Coordinated Agronomic Research Project.

ing have been found to increase the yield significantly, by about 10 to 15%. Combination of inoculation and side dressing of slurry showed synergistic effect by increasing yield more than either individual treatment (Roy Sharma et al. 1979). Small yield increasesdueto inoculation have been generally observed (Saxena and Yadav 1975). There were indications that pelleting of inoculated seed with charcoal, lime, or talc might improve the performance of inoculant (Saxena et al. 1975) in order to protect the Rhizobia from the effects of acid fertilizers and dry or acid soils.

Economics of Fertilizer Use

The response of pigeonpea to fertilizer application on cultivators' fields (Anonymous 1973) was subjected to economic analysis (Table 9). A dose of 20 kg N, 40 kg P_2O_5, and 20 kg K_2O/ha was satisfactory in the medium black soil of Gulbarga, red sandy soil of Sundergarh, and mixed red and black soils of Phulbani, giving a benefit-cost ratio of Rs 1.28 to Rs 4.07 per rupee cost of fertilizer. In the red and laterite soil of Medak, application of 20 kg N and 40 kg P2O5 and 20 kg K_2O/ha gave a benefit-cost ratio of Rs. 6.35 and Rs. 8.80 per rupee cost of fertilizer with cvs S-5 and HY-3, respectively.

References

AHLAWAT, I. P. S. 1976. Response of arhar varieties to plant population densities and phosphorus under rainfed conditions. Ph.D. thesis, Agra University, Uttar Pradesh, India.

AHLAWAT, I. P. S., SINGH, A., and SARAF, C. S. 1975. Response of pigeonpea to fertilizer under rainfed conditions. Indian Journal of Agronomy 20: 63-64.

ANONYMOUS. 1973. Annual progress reports of the All India Coordinated Agronomic Research Project for 1972-73 to 1978. ICAR.New Delhi, India.

BAINS, S. S. 1970. Multiple cropping sequences. World Science News 7-17.

BHATAWADEKAR, P. U., CHINOY.S. S., and DESHMUKH, K. M. 1966. Response of Bajri-tur mixed crop to nitrogen and phosphate fertilization under dry farming condition of Sholapur. Indian Journal of Agronomy 11: 243-246.

CHOWDHURY, S. L. 1968. Response of red gram to varying fertility levels. *In* Proceedings, AICPIP Second Workshop, IARI, New Delhi, India.

CHOWDHURY, S. L., and BHATIA, P. C. 1971. Profits triple when arhar is adequately fertilized. Indian Farming 22: 27-30.

GUPTA, R. A., AGARWAL, M. C., and SAXENA, S. K. 1971. Response of short duration arhar (T-21) to date of sowing, row spacing and phosphorus application. Current Agriculture 1(3): 69-70.

HEGDE, D. M. 1977. Phosphorus management in intercropping with pigeonpea under dryland conditions. Ph.D. thesis, IARI, New Delhi, India.

KALYAN SINGH and PRASAD, R. 1975. It pays to fertilize arhar under rainfed conditions. Fertilizer News 20(2): 28-30.

KAUL, J. N., and SEKHON, H. S. 1975. Response of pigeonpea to dates of planting and phosphorus levels. Indian Journal of Agronomy 20(4): 376-377.

KHAN, A. R., and MATHUR, B. P. 1962. Studie on tillage XIII. Effects of varieties and the depth of cultivation with different methods of phosphate application on the yield of pigeonpea. Indian Journal of Agricultural Sciences 32: 35-38.

KHEDEKAR, P. K. 1976. Pages7-10and 13-15/n Report of research work done at Punjabrao Krishi Vidya Peeth, Akola. Twelfth Meeting of the Agronomy and Soil Science Subcommittee, Akola, Maharashtra, India.

KRAUSS, P. G. 1932. The pigeonpea, its culture and utilization in Hawaii. University of Hawaii Agricultural Experiment Station Bulletin 64, Honolulu, Hawaii, USA.

LENKA, D., and SATPATHY, R. K. 1976. Response of pigeonpea varieties to levels of nitrogen and phosphate in laterite soil. Indian Journal of Agronomy 21(3): 217-220.

MAMORIA, C. B. 1976. Agricultural problems of India, 8th ed. Allahabad, India: Kitab Mahal.

MANJHI, S., CHOWDHURY, S. L., and KAVITKAR, A. G. 1973. Influence of varieties, planting dates, row spacing and fertilizer nutrients on the yield and yield components of pigeonpea. Indian Journal of Agricultural Sciences 43(11): 998-1001.

MOHD. YASEEN. 1979. Review of work done in arhar agronomy in Andhra Pradesh. Andhra Pradesh Agricultural University, Hyderabad, India.

MUKHERJEE, S. P. 1979. Strategy for increasing the production of pulses and oilseeds in irrigated commands. Presented at the National Workshop on Development of Action Plan for Increasing Production of Pulses and Oilseeds. IARI, 25-26 June 1979, New Delhi, India.

PANWAR, K.S. 1975. Report of the work done on kharif pulses agronomy (1974-75) at CSAUAT, Kanpur. Presented at the 11th Annual AICPIP Workshop on Kharif Pulses, IARI, 9-12 June 1975, New Delhi, India.

PANWAR, K. S. 1977. Advances in agronomy of kharif pulses. Presented at the Training Seminar on Pulse Production Technology. C. S. Azad University of Agriculture and Technology, 6-8 July 1977, Kanpur, India.

PANWAR, K. S. 1979. Review and recommendations of the research work done on cultural practices for increasing production of pigeonpea. Presented at the Summer Institute on Production Technology of Pulses. Haryana Agricultural University, June-July 1979, Hissar, Haryana, India.

PANWAR, K.S. 1980. Review of efficient fertilizer use in kharif pulses and oilseeds. Presented at the FAI-BHU Seminar on Efficient Fertilizer Use in Kharif Crops. Banaras Hindu University, 14-15 March 1980, Varanasi, India.

PANWAR, K. S., and MISRA, A. S. 1973. Recommendations for the agronomy of kharif pulses. Presented at the Ninth Annual AICPIP Workshop on Kharif Pulses. IARI, 7-9 June 1973, New Delhi, India.

PANWAR, K. S., and YADAV, H. L. 1978. Response of short duration pigeonpea (T-21) to summer planting and phosphorus in parallel multiple cropping. Presented at the Annual AICPIP Workshop on Kharif Pulses. Baroda, India.

PATHAK, G. N. 1970. Red gram. Pages 14-53/n Pulse crops of India (ed. P. Kachroo). New Delhi, India: ICAR.

RAIKHEIKAR, S. V., QUADRI, S. J., and DESHMUKH, N. D. 1976. Fertilizer requirement of Arhar crop. Presented at the Group Meeting of Pulse Agronomists. IARI, 21-22 May 1976, New Delhi, India.

RAM, S., and GIRI, G. 1973. A note on response of red gram varieties to varying fertility levels. Indian Journal of Agronomy 18: 103-104.

RAMANUJAM, S. 1972. Some salient results of Pulse Research (2), Indian Farming 21(11): 19-21.

RAO, J. V. 1974. Studies on fertilizer management of wheat in maize-wheat and arhar-wheat cropping Systems. Ph.D. thesis, Indian Agricultural Research Institute, New Delhi, India.

RATHI, K. S., and TRIPATHI, H. N. 1978. Response of Arhar T-21 to date of planting, row spacing and phosphorus levels. Indian Journal of Agronomy 23(3).

RATHI, S. S., SINGH, D, MALIK, R. S. 1974. Responses of short duration arhar to dates of sowing, row spacing and phosphate application. Fertilizer News 19: 27 and 31.

ROY SHARMA, R. P., SHARMA, H. M., and THAKUR, H. C. 1979. Results of agronomic researches. Presented at the Pigeonpea Scientists' Meeting. 6—8 March 1973, Pusa, Bihar, India.

SAXENA, M. C, and YADAV, D. S. 1975. Some agronomic considerations of pigeonpea and chickpea. Pages 32-62 *in* Proceedings, International Workshop on Grain Legumes, ICRISAT, 13-16 Jan 1975, Hyderabad, India.

SAXENA, M. C, and SINGH, Y. 1970. Relative susceptibility of important varieties of some pulses and soybean to zinc deficiency. Presented at the Third Annual Workshop on Coordinated Scheme on Micro-nutrients of Soils, 5-7 Oct 1970, Ludhiana, India.

SAXENA, M. C, TILAK, K. V. B. R., and YADAV, D. S. 1975. Response of pigeonpea to inoculation and pelleting. Indian Journal of Agronomy 20(4): 321-324.

SINGH, K., PRASAD, R., and CHOWDHURY, S. L. 1976. Effect of N, P, and Rhizobium inoculation on growth and yield of pigeonpea under rainfed conditions. Indian Journal of Agronomy 21(1): 49-53.

SINGH, K. B. 1973. Punjab farmer can take on arhar in a big way. Indian Farming 22: 19.

SINGH, D., and RATHI, K. S. 1972. Balanced fertilizer use in pulse crops. Seminar on Balanced Fertilization of Commercial Crops. FAI and Uttar Pradesh Department of Agriculture, 25 Oct 1972, Lucknow, India.

USDA (United States Department of Agriculture). 1968, Pages 123-187 *in* USDA Agriculture Research Service and U.S. Agency for International Development Progress Report 6,Washington DC, USA.

Micronutrient Research in Pigeonpea

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Abstract

Pigeonpea is a major pulse crop in India, which produces 90% of the world total. Yet work on mineral nutrition of this crop, particularly micronutrient nutrition, has so far been negligible. The soils on which pigeonpea is grown contain lime and are low in organic matter — a combination known to favor micronutrient deficiencies. However, critical limits at which these can occur have not yet been established, and little is known of the role of micronutrients in nitrogen fixation, the field response to micronutrient application, or the effects of deficiencies on yields. Available information on these topics is reviewed in this paper and future research needs outlined. Because pigeonpea is a high-risk crop in the SA T, the farmer is unlikely to use costly fertilizer; hence, emphasis should be on selecting varieties that tolerate nutrient stress.

Probable Areas of Micronutrient Deficiency

Pigeonpea is mainly a crop of arid and semi-arid climates, where it is cultivated largely as a rainfed crop. The soils of these regions, though variable, are, by and large, poor in fertility (Kanwar 1976; Sanchez and Cochrane 1979). On the Indian subcontinent, pigeonpea is grown mainly on Alfisols (Aubert and Tavernier 1972, quoted by Kampen and Burford 1979) and on Vertisols. These soils are low in organic matter content and invariably have lime in their profiles, a combination known to favor deficiencies of all the micronutrients, except molybdenum.

Kampen and Burford (1979) have suspected widespread marginal zinc deficiency in these areas. This contention is supported by micronutrient analysis of a large number of soil samples, done under the auspices of the ICAR's All India Coordinated Scheme of Micronutrients in Soils and Plants (Table 1). For instance, out of 22 347 soil samples analyzed in the major pigeonpea-growing states of Andhra Pradesh, Bihar, Karnataka, Madhya Pradesh, and Uttar Pradesh, 47% were categorized zinc deficient. The deficiencies of the remaining cations appear unimportant from these data. However, the critical limits used to isolate the deficient soil samples might not conform to those for pigeonpea; hence, the extent of micronutrient-deficient area for this crop is debatable. Nonetheless, this information, revealing the probability of widespread zinc deficiency, can be used as a first approximation. Thechances of zinc deficiency also increase because arid soils are generally low in zinc content (Nair and Cottenie 1971). Furthermore, erosion being a serious problem in these soils (Sanchez and Cochrane 1979), the washing away of micronutrient-rich topsoil may also contribute to zinc deficiency.

In marked contrast to the low zinc content of soils of arid and semi-arid regions, the boron contents are reported to be generally higher than in soils of the humid zones (Kanwar and Shah Singh 1961). The high boron content, however, may not insure against boron deficiency, because free lime in these soils diminishes boron availability and may thus cause boron problems.

High pH depresses the availability of zinc, iron, manganese, copper, and boron. On the contrary, it enhances the availability of molybdenum; hence, the alkaline soils of arid and semi-arid regions may not pose a molybdenum problem for pigeonpea. However, the mo-

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Table 1. MIcronutrient deficiencies in soil samples from major pigeonpea-g rowing states of India[a].

State	Zinc		Copper		Manganese		Iron	
	No. of samples	Deficiency (%)	No. of samples	Deficiency (%)	No. of samples	Deficiency (%)	No. of samples	Deficiency (%)
Andhra Pradesh	2 753	54	2 076	0	2 076	1	2 076	<1
Bihar	7 929	40	7 397	<1	6 150	2	6 375	3
Karnataka	2 153	21	2 153	4	2 153	1	2 153	<1
Madhya Pradesh	4 601	58	3 744	2	3 759	8	4 028	7
Uttar Pradesh	4911	57	3 916	<1	3 592	<1	4 388	6
	22 347	46	19 286	1	17 730	3	19 020	4

Source: All India Coordinated Scheme of Micronutrients in Soils and Plants (ICAR), 12th Annual Report, 1978-79.
a. Data for Maharashtra State not available

lybdenum requirements of the nodule bacteria may differ from those of the host. Therefore it is not certain whether these soils contain sufficient amounts of this element to support optimum *Rhizobium* growth, multiplication, and functioning.

Functions of Micronutrients

The specific functions of micronutrients in pigeonpea are probably not different from those in other crops. However, like any other leguminous crop, pigeonpea is capable of fixing atmospheric nitrogen. This process of symbiotic nitrogen fixation requires molybdenum for incorporation into the key enzyme, nitrogenase (Dilworth 1974). Perhaps on account of this, the molybdenum requirements of *Rhizobium* are much higher than those of the host plant. That relatively smaller amounts of this nutrient element are required by the host plant is proven by the lack of response of large-seeded legumes growing on molybdenum deficient soils. Apparently, this is associated with the adequate molybdenum content of the seed itself (Hewitt et al. 1954).

Cobalt deficiency may also retard nitrogen fixation, since cobalt is reported to be essential for symbiotic nitrogen fixation (Ahmad and Evans 1960), and for rhizobial growth (Cowles et al. 1969). Dilworth et al. (1979) and Robson et al. (1979) related the depressive effect of cobalt deficiency on nitrogen fixation in lupines to reduction in bacteroid density, to reduction in leghemoglobin content, and to the delay in the initiation of acetylene-reducing activity. In contrast to these observations, decreased growth of lupines and increased nitrogen concentration in the tops have been observed in some instances, suggesting thereby that cobalt has some unknown functions other than nitrogen fixation (Gladstone et al. 1977). Lupines have exhibited a particular sensitivity to cobalt deficiency (Gladstone et al. 1977; Chatel et al. 1978); however, it needs to be settled to what degree pigeonpea will respond to this stress.

Boron has been implicated in poornodulation of sweetpeas (Mulder 1948) and, as a consequence, in inducing nitrogen deficiency. However, when the crop was fertilized with nitrogen, the nitrogen deficiency disappeared, but boron deficiency became evident. From the consideration of specific functions of boron in cell divison and elongation of growing points, it may be inferred that the interference of boron deficiency in nitrogen fixation seems to be associated more with poor root growth than with inhibition of nodulation (Loneragan 1979). Similarly, though iron is a constituent of nitrogenase and leghemoglobin, this does not necessarily amount to dependence of nitrogen fixation on this element. This contention is supported by the work of Nichols (1965), who demonstrated only a marginal effect of iron deficiency on nitrogen fixation by pigeonpea. The role of copper in nitrogen fixation is also not fully understood. Several workers (Greenwood and

Hallsworth 2960; Cartwright and Hallsworth 1970) have reported that nitrogen fixation in subterranean clover was markedly reduced by copper deficiency; strikingly, however, nitrogen fixation in peanuts was not affected (Naulsri 1977, quoted from Loneragan 1979).

Deficiency Symptoms

The work on characteristic deficiency symptoms of various micronutrients in pigeonpea is scanty. The involvement of certain micronutrients in nitrogen fixation leads to a confusing picture. Available information on micronutrient deficiency symptoms is reviewed here.

Zinc Deficiency

Zinc deficiency symptoms in pigeonpea grown in sand culture have been described by Agarwala and associates (1973). Reddy et al. (1978) and Shukla and associates (1976) described these in plants growing in zinc-deficient soils. The first symptoms appeared within 3 weeks of sowing:

1. Plants showed stunted growth, narrowing of leaflets, pale green or yellow appearance, and general loss of vigor.
2. Interveinal chlorosis started from the top of the trifoliate leaf on all three leaflets and spread to the remaining areas, leaving only the midrib green.
3. Leaflet curling and shedding was observed when two-thirds of the leaflet became chlorotic.

Iron Deficiency

The symptoms of iron deficiency in pigeonpea growing in solution culture have been discussed by Nichols (1964). Since iron is immobile in the plant, the youngest leaves showed the symptoms first. Interveinal areas became pale green. In severe cases, the entire area of the leaflet became chlorotic and small necrotic patches developed.

Manganese Deficiency

In pigeonpea growing in sand culture, less than 0.0055 ppm manganese supply gave a slight depression in growth after 16 days of sowing (Agarwala and associates 1978), whereas in 21-day-old plants, the symptoms of manganese deficiency were observed as a fading of the green color of the lamina of the middle leaves. The veins were unaffected. Following this, small white and brown spots, first appearing in the chlorotic areas, coalesced and formed brown necrotic lesions. Manganese deficiency caused a reduction in the leaf size, leaf number, and leaf area. The growth of the apical shoot was arrested and flowering was markedly delayed.

Boron Deficiency

Boron deficiency resulted in dieback, rosetting, multiple branching, and death of seedlings (Reddy et al. 1978).

Other Micronutrient Deficiencies

Symptoms of the remaining micronutrient deficiencies have not been described for pigeonpea. However, molybdenum deficiency, like nitrogen deficiency, may lead to general yellowing of the plant.

Micronutrient Contents

Little is known aboutthe micronutrient contents of pigeonpea growing under diverse soil and climatic conditions. The available information on analytical results is presented in Table 2.

In pigeonpea, as in any other crop, micronutrient contents vary considerably with the age of the crop, the plant part samples, and nutrient interactions (Dalai and Quilt 1977; Dalai 1980). Iron and manganese were found to be the highest in the lowest branches, and zinc tended to concentrate mainly in the upper branches, but copper was evenly distributed in the plant. The differences in distribution of micronutrients in various plant parts narrowed down as the plant approached flowering. Strikingly, more than half of the dry matter and nutrient elements were accumulated between flowering and maturity.

Fertilizer phosphorus caused a marked reduction in the zinc content of the plant (Dalai and Quilt 1977). Rise in pH antagonized the uptake of all the nutrient cations; manganese was the most adversely affected.

Table 2. Micronutrient contents of pigeonpea.

Micro-nutrient	Range (PPM)	Levels below which deficiency symptoms were observed (PPM)	Type of culture	Reference
Zn	14-45	14	Soil, pot culture	Reddy et al. 1978
	10-38	15	Soil, pot culture	Shukla and associates 1976
	25-52	30	Sand culture	Agarwala and associates 1973
	26-30	SNO[a]	Field experiment	Dalai and Quilt 1977
Cu	18-21	SNO	Field experiment	Dalai and Quilt 1977
Mn	4-6	SNO	Field experiment	Dalai and Quilt 1977
	5-31	8	Sand culture	Agarwala and associates 1978
Fe	108-160	SNO	Field experiment	Dalai and Quilt 1977
	61-193	61	Solution culture	Nichols 1965

a. SNO = Symptoms not observed.

Because there are no critical limits established of various micronutrients in pigeonpea, knowledge of the total contents is of limited value. These data do not reflect the limit of each micronutrient at which the occurrence of deficiency may be predicted. Nonetheless, an evaluation of these data (Shukla et al. 1976; Reddy et al. 1978; Nichols 1965; Agarwala and associates 1973, 1978) revealed that:

1. Pigeonpea growing in soil culture suffered from zinc deficiency if it tested less than 15 ppm Zn.; in sand culture, however, the zinc-deficient plants showed around 30 ppm Zn.
2. When the whole plant contained less than 8 ppm Mn, it exhibited manganese deficiency.
3. Pigeonpea grown in solution culture showed chlorosis with less than 65 ppm Fe.

Responses to Micronutrient Application

Pigeonpea grown in pots has been reported to respond to zinc application in a Seirozem soil from Hissar (Shukla and associates 1974) and a Vertisol from Andhra Pradesh (Reddy et al. 1978). The latter workers also observed the favorable effect of boron spray. Dalai and Quilt (1977) could not show benefits of molybdenum fertilization in field-grown pigeonpea on an acid soil. With the exception of this limited information, the response of pigeonpea to the other micronutrients or its field response to micronutrient application have neither been observed nor widely explored.

Pigeonpea cultivated in arid and semi-arid tropics is a high-risk crop. The farmer is reluctant to use even major nutrients despite proven responses to their application (Chaudhary and Bhatia 1971; Veeraswamy et al. 1972; Dalai and Quilt 1977). Thus, even if the occurrence of micronutrient deficiency disorders is established, farmers are not likely to apply required micronutrients.

One way to cut down fertilizer costs is to grow those crop varieties that can tolerate nutrient stress better than others. Genetic control of plant nutrition is well established (Brown et al. 1972). Isolation of varieties tolerant to a nutrient deficiency and their adoption on known deficient soils will make cultivation of pigeonpea more economical.

Results of a few screening experiments do indicate differential response of pigeonpea genotypes to zinc deficiency (Agarwala and associates 1973; Shukla and associates 1976); for instance, varieties Pant A-3 and Prabhat appeared to be more tolerant than others (Table 3). Based on the same criteria, H-72, Pant A-1, and T-21 were the most vulnerable to zinc deficiency. However, field tolerance of these varieties is unknown. This needs to be verified.

Table 3. Grain yield of seven pigeonpea varieties with and without zinc application.

Cultivar	Yield (g/pot) at zinc application level of		Reduction in yield from Zn_5 to Zn_0
	5 ppm	0 ppm	(%)
H 72-44	7.4	3.3	55
H 73-20	9.2	5.3	42
Pant A-1	11.4	3.8	67
Pant A-2	8.7	4.4	49
Pant A-3	10.0	6.7	38
Prabhat	9.9	6.1	38
T-21	8.5	3.8	55

Source: Shukla and associates 1976.

Future Research Needs

The history of micronutrient research reveals that the need for micronutrient application was felt at a time when the low-yield traditional agriculture made way for high-yield modern agriculture. For example, the improved wheat and rice varieties were introduced in the mid-1960s; in the late 1960s, micronutrient deficiencies were discovered to be an obstacle to higher yields. This was linked, among other factors, with greater depletion of soil micronutrient reserves as a result of high dry-matter production. In pigeonpea, such a situation will obviously not prevail until the existing low-yield barrier is broken.

Nonetheless, there is a need to:

1. establish critical limits of micronutrients in soils and plants;
2. survey pigeonpea-growing soils for their micronutrient supplying capacity, catalog probable deficiencies, and demarcate the deficient areas;
3. explore the association between micronutrient deficiencies and nitrogen fixation; and
4. find economic ways of alleviating nutritional disorders, chiefly by selecting varieties that tolerate nutrient deficiencies better than others.

References

AGARWALA, S. C., and ASSOCIATES 1973. Annual progress report of the ICAR All India Coordinated Scheme of Micronutrients in Soils and Plants for Lucknow University 1973-74. Lucknow University, Lucknow, Uttar Pradesh, India.

AGARWALA, S. C, and ASSOCIATES 1978. Annual progress report of the ICAR All India Coordinated Scheme of Micronutrients in Soils and Plants for the Lucknow University 1978-79. Lucknow University, Lucknow, Uttar Pradesh, India.

AHMAD, S., and EVANS, H. J. 1960. Cobalt: a micronutrient element for the growth of soybean plants under symbiotic conditions. Soil Science 90:205-210.

BROWN, J. C, AMBLER, J. E., CHANEY, R. L., and FOY, C. D. 1972. Differential response of plant genotypes to micronutrients, Pages 389-413 *in* Micronutrients in agriculture, eds. J. J. Mortvedt, P. M. Giordano, and W. L. Lindsay. Madison, Wisconsin, USA: Soil Science Society of America.

CARTWRIGHT, B., and HALLSWORTH, E. G. 1970. Effect of copper deficiency on root nodules of subterranean clover. Plant and Soil 33: 685-698.

CHATEL, D. L., ROBSON, A. D., GARTRELL, J. W., and DILWORTH, M.J. 1978. The effect of inoculation and Co application on the growth of and nitrogen fixation by sweet lupines. Australian Journal of Agricultural Research 29: 1191-1202.

CHAUDHARY, S. L.,and BHATIA, P.C. 1971. Profits triple when arhar is adequately fertilized. Indian Farming 20: 27-30.

COWLES,J.R.,EVANS, H. J., and RUSSELL, S. A. 1969. B_{12} Co enzyme dependent ribonucleotide in *Rhizobium* species and the effect of Co deficiency on the activity of the enzyme. Journal of Bacteriology 97: 1460-1465.

DALAL, R. C. 1980. Nutrient element concentration and dry matter production by field grown pigeonpea *(Cajanus cajan* [L] Millsp.). Tropical Agriculture (Trinidad) 57: 107-112.

DALAL, R. C, and QUILT, P. 1977. Effects of N, P, liming and Mo on nutrition and grain yield of pigeonpea. Agronomy Journal 69: 854-857.

DILWORTH, M. J. 1974. Dinitrogen fixation. Annual Review of Plant Physiology 25: 81-114.

DILWORTH, M. J., ROBSON, A. D., and CHATEL, D. L. 1979. Cobalt and nitrogen fixation in *Lupinus angustifolius* L. II. Nodule formation and function. New Phytology 83: 63-79.

GLADSTONE, J. S., LONERAGAN, J. F., and GOODCHILD, N. A. 1977. Field response to cobalt and molybdenum by different legume species with inferences on the role of cobalt in legume growth. Australian Journal of Agricultural Research 28: 619-628.

GREENWOOD, E. A. N., and HALLSWORTH, E. G., 1960. Studies on the nutrition of the forage legume. II. Some interactions of calcium, phosphorus, copper and molybdenum on the growth and chemical composition of *Trifolium subterraneum* L. Plant and Soil 12: 97-127.

HEWITT, E. J., BOLLE-JONES, E. W., and MILES, P. 1954. The production of copper, zinc and molybdenum deficiencies in crop plants grown in sand culture, with special reference to some effects of water supply and seed reserves. Plant and Soil 5: 205-222.

KAMPEN, J., and BURFORD, J. R. 1979. Production systems, soil-related restraints, and potentials in semi-arid tropical regions of Asia, Africa, and Latin America. Presented at the International Conference on Priorities for Alleviating Soil-Related Constraints to Food Production in Tropics. International Rice Research Institute, 4-8 June 1979, Los Banos, Philippines.

KANWAR, J. S. 1976. Soil fertility: theory and practice. New Delhi, India: Indian Council of Agricultural Research.

KANWAR, J. S., and SHAH SINGH, S. 1961. Boron in normal and saline alkaline soils of the irrigated areas of the Punjab. Soil Science 92: 207-211.

LONERAGAN, J. F. 1979. The response of legumes and pastures to micronutrients. Presented at the India/FAO/Norway Seminar on Micronutrients in Agriculture. 15-19 Sept 1979, New Delhi, India.

MULDER, E.G. 1948. Importance of molybdenum in the nitrogen metabolism of microorganisms and higher plants. Plant and Soil 1: 179-212.

NAIR, P. K. P., and COTTENIE, A. 1971. Parent material soil relationship in trace elements — a quantitative estimation. Geoderma 5: 81-97.

NICHOLS, R. 1964. Studies on the major element deficiencies of the pigeonpea *[Cajanus cajan)* in sand culture. I. Foliar symptoms of major element deficiencies. Plant and Soil 21: 377-387.

NICHOLS, R. 1965. Studies on the major element deficiencies of pigeonpea (*Cajanus cajan*) in sand culture. II. The effects of major element deficiencies on nodulation, growth and mineral composition. Plant and Soil 22: 112-126.

REDDY, P. R., SUBBARAO, I. V., and MADHUSUDAN RAO, L. 1978. Nutritional disorders in pigeonpea (*Cajanus cajan,* [L] Millsp.) Cv. Hy-3c and remedial measures. Science and Culture 44: 36-37.

ROBSON, A. D., DILWORTH, M. J., and CHATEL, D. L. 1979. Cobalt and nitrogen fixation in *Lupinus angustifolius* L. I. Growth, nitrogen concentration and cobalt distribution. New Phytology 83: 53-62.

SANCHEZ, P. A., and COCHRANE, T. T. 1979. Soil constraints in relation to major farming systems of tropical America. Presented at the International Conference on Priorities for Alleviating Soil-Related Constraints to Food Production in the Tropics: International Rice Research Institute, 4-8 June 1979, Los Banos, Philippines.

SHUKLA, U. C, and associates. 1976. Annual progress report of the ICAR All India Coordinated Scheme of Micronutrients in Soils and Plants for Haryana Agricultural University 1976-77. Haryana Agricultural University, Hissar, Haryana, India.

SINGH, K. B., and VIRMANI, S. S. 1974. Cultivation of pulses in the Punjab. Punjab Agricultural University, Ludhiana, Punjab, India.

VEERASWAMY, R., RAJASEKARAN, V. P. A., SELVAKUMARI, G., and SHERIF, N. M. 1972. Effects of phosphoric acid and organic manure on red gram *(Cajanus cajan* [L] Millsp.). Madras Agricultural Journal 59: 304-305.

Uptake of Nutrients in Pigeonpea under Differing Management Conditions

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Abstract

In this paper, various aspects of nutrient uptake in pigeonpea in relation to crop management factors are discussed. All the management factors (cultural, manurial, and cropping systems) that have direct or indirect bearing on the productivity of the crop have been reported to influence the rate and total uptake of various mineral nutrients. However, the information on the whole is meager and therefore requires further detailed investigation under different agroclimatic conditions. The changes in the mineral nutrient composition of various plant organs at various stages of plant development under differing management conditions and their impact on rate and total removal need elaborate studies.

Nutrient uptake in crops is largely dependent on the growth and development of plants. However, concentration of various nutrients in the plant system also affects their total uptake, but the differences among the cultivars of a particular crop under similar management conditions are generally marginal. Therefore, the total biological yield produced determines to a large extent the quantum of nutrient uptake. Agro-practices or management also claim paramount importance in plant growth and development. The mode and pattern of nutrient uptake under differing management conditions in crops like cereals have been extensively investigated, but little detailed information is available on this aspect of pigeonpea in India and abroad. Here an effort has been made to compile whatever little information is available on these aspects in relation to different management conditions.

Nutrient Uptake

A crop of pigeonpea cv Pusa Ageti producing about 2 metric tons (tonnes) grain (G) and 6 tonnes sticks (S), has been reported to remove about93.5 kgN(59.5kgG + 34.0 kg S), 11.1 kg P (5.9 kg G + 5.2 kg S) and 53.3 kg K (26.2 kg G + 27.1 kg S) per ha (Rao 1974). On an average, 115 kg N and 16 kg P were removed by a crop yielding about 2 tonnes grain and 5.4 tonnes sticks/ha on the sandy loam soil of the Indian Agricultural Research Institute, New Delhi (Singh 1973). In sandy loam laterite soils of Bhubaneshwar, a crop yielding about 1.1 tonnes grain and 4.5 tonnes sticks removed 40 kg N and 8.0 kg P/ha (Lenka and Satpathy 1976). Mehta and Khatri (1962) reported removal of 29 kg N, 4kg P, 8.3kg K, 12kg Ca, and 5 kg Mg/ha by a crop producing 1630 kg total dry matter/ha.

Pattern of Nutrient Uptake

The increases in dry matter and absorption of mineral nutrients occur continuously in the plant, reaching peak assimilation/accumulation rates between flowering and seed setting. Leaves are generally richer in calcium and magnesium than other plant parts at all growth stages. Nitrogen, phosphorus, and potassium are greater in seeds than in other tissues. The nitrogen content in leaf laminae and stem declines with the age of the plant, as does the nitrogen content in peduncles and pods. The nitrogen percentage in leaves declines drastically from 4 or 5% to 1.5% at the time of abscission, indicating that two-thirds of the nitrogen in leaves is remobilized into the plant during leaf senescence.

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The phosphorus content in all the plant organs also declines throughout the growing period. The uptake continues during the reproduction phase also. The decline in amount of phosphorus in leaves during the reproductive phase is relatively larger than in stems. Like the nitrogen uptake rate, the phosphorus uptake rate is also found maximum in the later part of the vegetative phase and declines during the reproductive phase.

Crop Management and Nutrient Uptake

Management factors, which are always a governing factor in the productivity of crops, also determine the extent and pattern of nutrient uptake at various stages of crop growth. The mode and pattern of nutrient uptake under various important management factors is discussed here.

Cultivars differ considerably in their duration, rooting and nodulation pattern, biological yield, and harvest index. These factors individually or together cause variations in the uptake of various mineral elements. Manjhi (1971) reported that among the three pigeonpea cultivars, T-21, AS-8, and AS-10, the last removed the maximum amount of nitrogen at all stages except 60 days after planting, where T-21 had the highest nitrogen uptake (Table 1). Cultivar AS-10 also recorded highest phosphorus and potassium uptake at 30 and 90 days after plant-

Table 1. Pattern of nutrient uptake in pigeonpea cultivars.

	Days after planting				At harvest
	30	60	90	120	
A. SOURCE: MANJHM 1971					
Cultivar			N uptake (kg/ha)		
T-21	2.7	21.8	61.9	89.7	165.8
AS-10	3.1	20.3	63.8	94.1	216.2
AS-8	2.8	20.0	51.0	89.3	175.2
			P uptake (kg/ha)		
T-21	0.2	1.8	6.1	12.8	19.4
AS-10	0.2	1.6	6.4	12.0	24.4
AS-8	0.2	1.7	4.9	11.6	22.2
			K uptake (kg/ha)		
T-21	1.1	8.5	28.5	48.9	73.6
AS-10	1.2	7.8	31.4	45.1	95.8
AS-8	1.1	7.9	23.4	43.4	79.9
B. SOURCE: SINGH 11973					
Cultivar			N uptake (kg/ha)		
T-21	4.7	49.9	57.7		105.5
AS-3	4.5	48.3	70.6		115.5
AS-5	4.3	46.8	62.9		115.4
P-4785	4.0	44.8	60.4		121.5
			P uptake (kg/ha)		
T-21	0.5	4.2	7.2		14.1
AS-3	0.5	4.0	8.2		16.6
AS-5	0.4	3.9	8.0		16.3
P-4785	0.4	3.7	7.8		17.5

Continued

Table 1. *Continued*

	Days after planting			
	30	60	90	At harvest
C. SOURCE: SINGH 1978				
Cultivar		N uptake (kg/ha)		
Prabhat	10.4	55.3	66.4	101.0
UPAS-120	10.5	58.1	70.1	107.2
BS-1	10.5	53.0	70.3	118.8
LSD at 0.05	NS	0.7	0.9	2.7
		P uptake (kg/ha)		
Prabhat	0.9	6.3	8.0	13.5
UPAS-120	0.9	6.5	8.4	14.1
BS-1	0.9	6.1	8.2	15.5
LSD at 0.05	NS	NS	0.2	0.6

	Days after planting				
	40	60	80	100	At harvest
D. SOURCE: AHLAWAT 1977					
Cultivars			N uptake (kg/haj		
AS-5	7.6	37.5	52.7	58.1	91.8
P-4785	7.1	36.2	50.4	59.2	94.5
Prabhat	6.9	35.1	49.5	55.3	71.9
LSD at 0.05	NS	1.8	1.7	2.8	2.7
			P uptake (kg/ha)		
AS-5	0.6	4.3	6.2	6.7	12.3
P-4785	0.6	4.3	5.8	6.7	12.9
Prabhat	0.6	4.0	6.0	6.7	9.8
LSD at 0.05	NS	0.2	0.3	NS	0.4

NS - Not significant

ing and at harvest. At 60 and 120 days after planting, T-21 removed more phosphorus and potassium than AS-10 and AS-8. The biological yield of T-21 and AS-10 was almost identical at 120 days after planting, but the higher content of phosphorus and potassium in the seed of T-21 accounted for higher uptake of these mineral elements.

In medium-maturity cultivars (T-21, AS-3, AS-5, and P-4785), Singh (1973) found that the nitrogen and phosphorus uptake were not different until the 60-day stage. Cv AS-3 removed maximum nitrogen and phosphorus at 90 days after planting, but at harvest P-4785 had the highest nitrogen and phosphorus uptake because of higher biological yield and harvest index. P-4785 also recorded higher uptake of these elements at harvest than Pusa Ageti and Prabhat (Ahlawat 1977). Pusa Ageti had higher nitrogen and phosphorus uptake at the 80-day stage only. The short-duration cv Prabhat in general removed least nitrogen and phosphorus throughout crop growth.

In the early-maturity group, cv UPAS-120 removed maximum nitrogen at 60 days and phosphorus at 90 days, compared with Prabhat and BS-1; at harvest, BS-1 had the highest uptake on account of higher biological yield (Singh 1978).

Row Width

Closer row width tended to result in higher nutrient uptake in pigeonpea because of higher

Table 2. Effect of row width on nutrient uptake in pigeonpea.

	Days after planting				
	30	60	90	120	At harvest
A. SOURCE: MANJHI 1971					
Row width (cm)			N uptake (kg/ha)		
50	3.1	21.1	60.3	97.1	190.0
75	2.6	20.3	54.2	84.9	181.4
			P uptake (kg/ha)		
50	0.2	1.7	6.2	12.9	22.2
75	0.2	1.6	5.4	11.4	21.8
			K uptake (kg/ha)		
50	1.1	8.3	30.0	49.9	85.4
75	1.1	7.8	25.6	41.8	80.8
B. SOURCE: SINGH 1978					
Row width (cm)			N uptake (kg/ha)		
25	14.5	69.4	80.6		121.3
37.5	9.5	49.6	66.8		108.3
50	7.3	44.3	59.5		97.4
LSD at 0.05	0.4	0.7	0.9		2.7
			P uptake (kg/ha)		
25	1.2	8.1	9.2		15.1
37.5	0.8	5.5	8.0		14.6
50	0.6	5.2	7.4		13.5
LSD at 0.05	0.04	0.3	0.2		0.6

total dry-matter production per unit of area. Manjhi (1971) observed higher nitrogen, phosphorus, and potassium uptake in 50-cm spacing than 75-cm spacing (Table 2). Singh (1978) recorded higher nitrogen and phosphorus uptake in 25-cm than in 37.5-cm and 50-cm row widths at all stages of crop growth.

Planting Density

Planting density is one of the most important factors governing growth and development in the plant community. The nutrient uptake is generally positively correlated with the total dry-matter production. Thetotal biological yield per unit of area increases with the corresponding increase in the plant density within certain limits. Increased uptake of macronutrients (N, P, and K) in pigeonpea with the increase in plant density from 50 000 to 75 000 plants/ha was reported by Manjhi (1971) (Table 3). Ahlawat (1977) reported increase in nitrogen and phosphorus uptake with increasing plant densities in the range of 50 000 to 150 000 plants/ha (Table 3). Akinola and Whiteman (1975) tried a wide range of plant density (6727-215 278 plants/ha) in long-duration pigeonpea and observed that the total forage nitrogen yield increased with each increase in plant density (Table 4). However, the increases were marginal beyond 35 880 plants/ha. A density of 17 940 plants/ha produced significantly higher seed yield than lowest plant density of 6727 plants/ha and other plant densities higher than 17 940 plants/ha. Seed nitrogen yield, however, remained unaffected by plant density.

Rhizobial Inoculation

The effects of rhizobial inoculation on nutrient uptake are generally negligible. However, Singh (1973) obtained significant increase in nitrogen and potassium uptake at harvest by rhizobial inoculation in one out of the 2 years of experimentation (Table 5).

Table 3. Effect of plant density on nutrient uptake in pigeonpea.

	Days after planting							
	30	40	60	80	90	100	120	At harvest
A. SOURCE: MANJHI 1971								
Plant density (000/ha)					N uptake (kg/ha)			
50	2.3		18.3		47.7		77.7	181.6
75	3.4		23.2		66.8		104.3	189.9
					P uptake (kg/ha)			
50	0.2		1.5		4.8		10.5	21.6
75	0.3		1.9		6.8		13.8	22.5
					K uptake (kg/ha)			
50	1.0		7.1		23.2		39.7	80.9
75	1.2		9.0		32.4		51.9	85.3
B. SOURCE: AHLAWAT 1977								
Plant density (000/ha)					N uptake (kg/ha)			
50		3.9	21.9	30.6		36.3		64.4
100		7.3	39.4	54.2		60.7		91.3
150		10.4	47.6	67.7		75.5		102.5
LSD at 0.05		0.6	1.8	1.7		2.8		2.7
					P uptake (kg/ha)			
50		0.3	2.5	3.7		4.3		8.9
100		0.6	4.6	6.5		7.2		12.5
150		0.9	5.5	7.9		8.7		13.6
LSD at 0.05		0.04	0.2	0.3		0.2		0.4

Table 4. Effect of plant density on seed yield, forage, and seed nitrogen yield of pigeonpea.

Plant density	Seed yield (kg/ha)	Total forage nitrogen yield (kg/ha)	Seed nitrogen yield (kg/ha)
6 727	2559	204	90.8
8 970	2620	244	93.5
11 960	2672	284	94.9
17 940	2774	287	104.0
26 910	2267	326	84.3
35 880	1860	345	67.0
53 820	1648	353	60.2
107 639	1527	352	55.7
215 278	1522	355	57.8
LSD at 0.05	177	18	NS

NS = Not significant.
Source: Akinola and Whiteman 1975.

Nutrient Application and Nutrient Uptake

Nitrogen

Leguminous plants require nitrogen from an outside source only up to the stage of root-nodule formation. Thereafter, plants do not depend any more on soil or fertilizer nitrogen if there is proper nodulation on the roots. The general experience on nitrogen fertilization in grain legumes is not encouraging. Nitrogen application did not affect the uptake of macro-nutrients in pigeonpea (Singh 1973; Dalai and Quilt 1977) (Tables 5 and 6). Significant increase in manganese concentration obtained by nitrogen application was reported by Dalai and Quilt (1977) (Table 7). The effect was probably due to change in soil pH, since manganese concentration was significantly correlated with soil pH.

Phosphorus

Among the macronutrients, phosphorus is most important for legumes. Pigeonpea invariably responds to phosphorus application, except where soils contain high available phosphorus. Application of phosphorus has been reported to increase the nitrogen and phosphorus uptake in pigeonpea (Singh 1973; Ahlawat 1977; Hegde 1977; Dalai and Quilt 1977) (Tables 6 and 8). The effects of phosphate application on nitrogen and phosphorus uptake are generally marked in the later vegetative phase and continue throughout the reproductive phase (Singh 1973). Ahlawat (1977) observed that the higher rate of phosphate application (34 kg P/ha) removed more of nitrogen and phosphorus than 17 kg P/ha at some stages of the plant, but there was no difference at harvest. Dalai and Quilt (1977) noticed an increase in nitrogen and magnesium uptake at the higher level of P_2O_5 (250 kg/ha) only, whereas increase in phosphorus uptake was marked at 100 kg/ha level (Table 6). Phosphate application had no effect on potash and calcium uptake. Increase in potassium uptake at various growth stages by application of phosphorus was also reported by Hegde (1977). Phosphorus application significantly reduced the zinc con-

Table 5. Effect of rhizobial Inoculation and starter N on nutrient uptake in pigeonpea.

Factor	Days after planting 30	60	90	At harvest
	N uptake (kg/ha)			
No nitrogen, no inoculation	4.5	46.1	63.0	111.9
Inoculation	4.0	46.0	63.4	115.1
25 kg N/ha	6.6	50.5	62.4	112.7
	P uptake (kg/ha)			
No nitrogen, no inoculation	0.3	3.8	7.7	15.1
Inoculation	0.4	3.8	7.9	17.4
25 kg N/ha	0.4	4.3	7.7	15.7

Source: Singh 1973.

Table 6. Total uptake of K, Ca, Mg, N, and P by pigeonpea as affected by N, P, and lime application.

Factor level	Treatment N	P	Lime	K uptake N	P	Lime	Ca uptake N	P	Lime	Mg uptake N	P	Lime	N uptake N	P	Lim	P uptake N	P	Lime
0	0	0	0	92	99	83	78	77	65	36	35	28	239	244	217	31	28	24
1	10	50	1250	93	93	93	83	83	83	37	37	37	249	249	249	29	29	29
2	20	100	2500	99	91	107	74	76	88	32	33	40	255	231	257	29	37	36
3	30	250	5000	97	109	95	76	98	90	37	48	39	262	318	254	31	43	35
LSD at 0.05					29			22			10			69			8	

Source: Dalai and Quilt 1977.
LSD values apply to N, P, and lima treatments.

Table 7. Concentration of Cu, Zn, Fe, and Mn in pigeonpea as affected by N, P, and lime application.

Factor level	Treatment N	P	Lime	Cu cone. N	P	Lime	Zn cone. N	P	Lime	Fe cone. N	P	Lime	Mn conc. N	P	Lime
0	0	0	0	19.9	20.3	20.3	27.5	30.5	28.9	127	129	137	4.0	4.5	5.0
1	10	50	1250	17.5	17.5	17.5	27.1	27.1	27.1	128	128	128	4.5	4.5	4.5
2	20	100	2500	20.6	20.3	20.3	29.5	26.5	28.1	138	136	128	5.0	4.5	4.0
3	30	250	5000	16.8	17.8	20.3	28.5	26.3	28.0	160	108	114	5.5	5.3	3.8
LSD at 0.05					4.5			3.4			34			0.9	

Source: Dalai and Quilt 1977.
LSD values apply to N, P, and lime treatments.

Table 8. Nutrient uptake as affected by phosphate fertilization.

P_2O_5 kg/ha	Days after planting 30	60	90	At harvest	Days after planting 30	60	90	At harvest
A. SOURCE: SINGH 1973								
	N uptake (kg/ha)				P uptake (kg/ha)			
0	4.1	42.9	58.5	105.0	0.3	3.4	7.2	13.5
25	4.2	44.6	60.8	109.6	0.4	3.8	7.5	15.1
50	4.2	47.6	62.0	114.4	0.5	4.2	7.7	16.1
75	4.4	49.1	65.2	118.4	0.5	4.4	7.8	16.8
100	4.9	53.2	68.1	125.0	0.6	4.5	8.6	18.1

	Days after planting 40	60	80	100	At harvest	Days after planting 40	60	80	100	At harvest
B. SOURCE: AHLAWAT 1977										
	N uptake (kg/ha)					P uptake (kg/ha)				
0	6.8	31.9	44.7	49.8	68.7	0.6	3.3	5.0	5.3	8.8
40	7.2	37.5	53.2	59.7	94.1	0.6	4.6	6.4	7.1	12.9
80	7.7	39.5	54.9	63.0	95.4	0.7	4.8	6.7	7.8	13.3
LSD at 0.05	0.6	1.8	1.7	2.8	2.7	0.04	0.2	0.3	0.2	0.4

	Days after planting 35	65	95	At harvest
C. SOURCE: HEGDE 1977				
	N uptake (kg/ha)			
0	2.8	21.8	55.7	72.1
40	3.8	30.7	75.1	105.1
80	4.2	33.8	82.6	114.2
	P uptake (kg/ha)			
0	0.3	2.4	5.9	7.6
40	0.4	3.6	8.5	11.3
80	0.5	3.9	9.8	12.4
	K uptake (kg/ha)			
0	1.2	8.2	18.3	24.0
40	1.5	10.2	22.4	30.2
80	1.6	11.1	23.8	31.1

centration in the plant, whereas the concentration of copper, iron, and manganese remained unaffected (Dalai and Quilt 1977).

Nutrient Combinations

Manjhi (1971) reported that application of nitrogen, alone or in combination with phosphorus, increased the uptake of nitrogen, phosphorus, and potassium at various growth stages of the plant (Table 9). Combining potash with nitrogen promoted nitrogen and phosphorus uptake at some stages of the vegetative phase but had little advantage over nitrogen alone in respect of nitrogen, phosphorus, and potassium uptake at harvest. Phosphorus application with nitrogen and potash produced larger effects in nutrient uptake than nitrogen alone and nitrogen plus potash. Rao (1974) reported increased uptake *of* nitrogen, phosphorus, and potassium at all the growth stages with the increase in rates of nitrogen, phosphorus, and potassium in combination (Table 10).

Table 9. Effect of nutrient combinations (N, P, and K) on nutrient uptake in pigeonpea.

Factor symbol	Factor (Nutrients kg/ha)	Days after planting 30	60	90	120	At harvest
				N uptake (kg/ha)		
Fo	No fertilizer	2.0	16.3	48.7	75.7	151.3
F_1	25 N	2.8	19.4	55.4	82.6	177.1
F_2	25 N + 25 $K_2$0	2.9	20.3	58.7	91.6	184.3
F_3	25 N + 25 $K_2$0O+ 50P205	3.3	23.8	66.8	102.5	206.4
F4	25 N + 25K20+100p2Oe	3.4	23.8	71.7	102.8	209.6
				P uptake (kg/ha)		
Fo		0.1	1.4	5.0	10.6	17.7
F_1		0.2	1.6	5.5	11.3	22.3
F_2		0.2	1.7	5.8	11.8	21.7
F_3		0.2	1.9	6.2	13.5	23.7
F_4		0.3	2.0	6.5	13.6	24.6
				K uptake (kg/ha)		
Fo		0.9	6.6	24.9	40.7	67.9
F_1		1.1	7.7	27.9	43.5	82.5
F_2		1.1	8.2	27.9	45.1	84.7
F_3		1.2	8.7	28.8	51.1	89.9
F<		1.2	9.1	29.4	48.7	90.5

Source: Manjhi 1971.

Table 10. Effect of nutrient combinations on mineral nutrient uptake in pigeonpea.

Factor level	Treatment N	P2O5	K2O	Day after planting 40	70	100	130	At harvest
						N uptake (kg/ha)		
0	0	0	0	3.0	5.5	15.9	34.0	47.1
1	8	20	20	10.0	14.4	32.5	62.9	86.2
2	16	40	40	19.2	37.4	65.4	93.0	108.7
3	24	60	60	30.1	49.0	112.8	126.2	132.2
Percent of total				16.7	28.4	60.6	84.5	100.0
						P uptake (kg/ha)		
0				0.4	0.8	2.6	5.4	6.2
1				1.2	1.8	3.7	8.2	9.9
2				2.4	4.8	7.0	10.8	12.1
3				3.1	6.2	12.0	14.1	16.4
Percent of total				15.9	30.1	56.8	86.5	100.0
						K uptake (kg/ha)		
0				3.0	4.0	13.0	31.8	34.4
1				6.0	10.4	19.8	40.3	48.5
2				11.5	27.2	34.8	53.1	57.4
3				13.9	30.9	55.7	69.6	73.0
Percent of total				15.9	34.0	57.8	91.2	100.0

Source: Rao 1974.

Lime

Dalai and Quilt (1977) observed that liming did not affect nitrogen and potassium uptake but increased the phosphorus, calcium, and magnesium uptake (Table 6). Liming decreased the manganese concentration in the plant but had no effect on copper, zinc, and iron concentration (Table 7).

Cropping System and Nutrient Uptake

Crop Rotation

In a wheat-pigeonpea cropping sequence, phosphorus applied to the preceding wheat crop and directly to pigeonpea increased the uptake of mineral nutrients (N and P) in pigeonpea (Rao 1975) (Table 11). Increasing rates of P2O5 applied to the preceding wheat crop increased the uptake of nitrogen and phosphorus in pigeonpea, irrespective of the rates of P2O5 applied to the pigeonpea crop. The phosphorus uptake at the higher level of P2O5 (80 kg/ha) to the previous wheat crop and following pigeonpea was, however, not different from that at the lower level (40 kg/ha) to wheat and higher level (80 kg/ha) to pigeonpea. Similarly, nitrogen and phosphorus uptake increased with increasing rates of P2O5 applied to pigeonpea at all rates of P2O5 applied to preceding wheat.

Table 11. Nutrient uptake (kg/ha) in pigeonpea as influenced by phosphate fertilization in wheat-pigeonpea cropping sequence.

First phase

P2O5 applied to wheat (kg/ha)	P_2O_5 applied to pigeonpea (kg/ha)					
	0		40		80	
	N uptake	P uptake	N uptake	P uptake	N uptake	P uptake
0	111.0	13.6	144.1	17.7	166.8	20.6
40	121.5	15.0	149.5	18.7	169.5	21.8
80	138.2	17.0	157.0	20.2	175.9	21.4

Second phase

P_2O_5 (kg/ha) applied to					
Wheat	Pigeonpea	Wheat	Pigeonpea	N uptake (kg/ha)	P uptake (kg/ha)
0	0	0	0	90.6	10.7
40	0	0	0	94.9	11.0
80	0	0	0	94.0	11.3
0	40	0	0	94.9	11.2
0	80	0	0	97.4	11.6
0	0	40	0	106.4	12.6
0	0	80	0	120.5	14.2
40	40	0	0	97.0	11.2
80	80	0	0	104.2	12.1
80	40	0	0	98.7	11.9
40	80	0	0	97.4	11.8
0	0	0	40	123.9	15.1
40	40	40	40	138.4	16.7
80	80	80	80	147.4	18.0
LSD at 0.05				8.7	1.0

Source: Rao 1975.

Intercropping

Intercropping of short-duration grain legumes, namely mung bean, urd bean, and cowpea (grain or fodder) in pigeonpea adversely affected the uptake of nitrogen, phosphorus and potassium at various growth stages of the crop (Table 12). Cowpea (fodder) as intercrop affected the uptake of mineral nutrients most adversely (Hegde 1977).

Defoliation

Studies on defoliation with long-duration cultivars showed that the total nitrogen yield tended to increase with the advancement of time of defoliation. However, significant increase in nitrogen yield was observed at 16 weeks over 4 weeks (Akinola and Whiteman 1975) (Table 13).

Table 12. Nutrient uptake in pigeonpea as affected by intercropping of short-duration grain legumes.

Intercrop in pigeonpea	Nutrient uptake (kg/ha)											
	N uptake				P uptake				K uptake			
	Stages (days after planting)											
	35	65	95	At harvest	35	65	95	At harvest	35	65	95	At harvest
No intercrop	4.3	36.3	89.6	123.1	0.4	4.1	9.7	13.2	1.8	14.8	29.6	37.2
Mung bean	3.1	27.2	67.9	97.6	0.3	3.1	7.7	10.1	1.3	8.5	20.8	27.6
Urd bean	3.8	29.1	67.2	91.9	0.4	3.4	7.9	10.1	1.5	10.0	19.4	27.8
Cowpea (grain)	3.8	27.5	66.9	89.7	0.4	3.1	7.9	10.1	1.5	8.4	20.0	27.0
Cowpea (fodder)	3.1	23.6	64.0	82.7	0.3	2.7	7.2	8.8	1.3	7.3	17.8	22.5

Source: Hegde 1977.

Table 13. Total nitrogen yield (kg/ha) of tops defoliated to 90 cm at four frequencies over 48 weeks.

Defoliation frequency	Accession				
	UQ-1	UQ-38	UQ-37	UQ-39	Mean
4 weeks	312	331	234	145	257
8 weeks	369	358	259	201	300
12 weeks	410	341	290	198	310
16 weeks	460	445	172	216	323
Accession mean	388	369	239	191	
LSD at 0.05					
Defoliation			57		
Accession			51		
Accession means within same defoliation			102		
Defoliation means within same accession			105		

Source: Akinola and Whiteman 1975.

References

AHLAWAT, I. P. S. 1977. Response of *arhar (Cajanus cajan* [L.] Millsp.) varieties to plant population densities and phosphorus under rainfed conditions. Ph.D. Thesis, Agra University, Agra, U.P., India.

AKINOLA, J. O., and WHITEMAN, P. C. 1975. Agronomic studies on pigeonpea (*Cajanus cajan* [L.] Millsp.). III. Responses to defoliation. Australian Journal of Agricultural Research 26: 67-79.

DALAL, R. C., and QUILT, P. 1977. Effects of N, P, liming and Mo on nutrition and grain yield of pigeonpea. Agronomy Journal 69: 854-857.

HEGDE, D. M. 1977. Phosphorus management In intercropping with pigeonpea *(Cajanus cajan* [L] Millsp.) under dryland conditions. Ph.D. thesis, Indian Agricultural Research Institute, New Delhi, India.

LENKA, D., and SATPATHY, R. K. 1976. Response of pigeonpea varieties to levels of nitrogen and phosphate in laterite soil. Indian Journal of Agronomy 21: 217-220.

MANJHI, S. 1971. Response of three strains of pigeonpea to two rates of planting and two row spacings in conjunction with five fertility treatments. Ph.D. Thesis, Indian Agricultural Research Institute, New Delhi, India.

MEHTA, B. V., and KHATRI, P. D. 1962. Accumulation and movement of minerals in pigeonpea *(Cajanus cajan* [L.] Millsp.) plant. Journal of the Maharaja Sayajirao University, Baroda 11: 109-122.

RAO, J. V. 1974. Studies on fertilizer management of wheat in maize-wheat and *arhar*-wheat cropping systems. Ph.D. Thesis, Indian Agricultural Research Institute, New Delhi, India.

RAO, M. R. 1975. Direct, residual and cumulative effect of phosphate in maize-wheat and *arhar*-wheat cropping systems. Ph.D. Thesis, Indian Agricultural Research Institute, New Delhi, India.

SINGH, A. 1978. Response of short duration pigeonpea *(Cajanus cajan* [L.] Millsp.) varieties to varying row spacing and phosphorus levels under rainfed conditions. Ph.D. Thesis, Indian Agricultural Research Institute, New Delhi, India.

SINGH, K. 1973. Plant density, rhizobial inoculation and fertilization studies in pigeonpea *(Cajanus cajan* [L.] Millsp.). Ph.D. Thesis, Indian Agricultural Research Institute, New Delhi, India.

Response of Pigeonpea to *Rhizobium* Inoculation in India

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Abstract

Trials conducted under the AICPIP (All India Coordinated Project for Improvement of Pulses) on pigeonpea have clearly indicated that Rhizobium *inoculation of seed substantially increases yields. These trials also indicated that there exists a complex host genotype-rhizobial strain interaction that is further modified by prevailing environmental conditions and varies from location to location and year to year. Further research is needed to enable the manipulation of this system to ensure that the pigeonpea crop meets its own requirement by fixing atmospheric nitrogen and also leaves behind a residue for the succeeding crop.*

Cajanus cajan is one of the most important grain legume crops of India, cultivated on about 2.7 million ha, amounting to nearly 12% of the total area under grain legumes in the country.

An important aspect of pigeonpea production is the extent to which this crop utilizes atmospheric nitrogen through the symbiotic system. For the microbiologist, it is a problematic crop, as its root system goes a few meters deep and as such poses problems for surveying root-nodulation patterns in intact plants. In general, the nodulation status of this crop has been found to be rather poor.

Studies carried out under the All India Coordinated Project on Improvement of Pulses of the ICAR on the effect of inoculating pigeonpea seeds with rhizobial cultures have given some very interesting results. Out of 18 trials conducted in different agroclimatic zones during 1978 and 1979, although general increases in yields were recorded in all the trials, statistically significant increase in grain yield was seen only in eight. Grain yield increases of 7 to 51% over the noninoculated control have been observed over 2 years at several locations. The quantum of actual increase has varied from 70 kg/ha to 530 kg/ha. It is to be noted that such observed increase was over a reasonably good control yield of around 1100 kg/ha (Tables 1, *2,* 3, 4). Such response to inoculation was noted both in new areas such as Ludhiana (Punjab), Hissar (Haryana), and Sardarkrishinagar (Gujarat) and in traditional pigeonpea-growing areas such as Gulbarga (Karnataka), Badnapur (Maharashtra), Jabalpur (Madhya Pradesh), and Hyderabad (Andhra Pradesh).

Nodulation in Pigeonpea

Nodule number or nodule weight does not seem to have any correlation with the efficiency of the rhizobial strain in terms of increment in grain yield. For example, nodule number and weight due to inoculation are about equal with strain KA-1 and F-4 at Gulbarga, BDN-A2 and CC-1 at Badnapur, and Multistrain and F-4 at Coimbatore, but there is a wide variation in the grain yield due to these strains. On the other hand, at Kaveripattinam, strain IHP-195 gave about half the number of nodules and weight as compared with Multistrain inoculant, whereas the yields were more or less at par (Tables 5,6,7).

At Jabalpur (Table 6) strain IHP-195 recorded significantly higher nodule number and weight than JNKVV-1, but the increase in grain yield duetotheformer was only 24% versus 51% due to the latter strain. Similarly, these nodular parameters due to CC-1 and JNKVV-1 were at par, while 39% more yield was recorded due to inoculation with the latter strain over the former

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Table 1. Response of pigeonpea to *Rhizobium* inoculation.[a]

Location	Year	Strain	Yield (kg/ha)		Increase over control	
			Control	Inoculated	(kg/ha)	(%)
Gulbarga	1978	KA-1	795	997	202	25
	1979	KA-1	1233	1320	87	7
	Average		1014	1159	145	14
Badnapur	1978	BDN-A_2	416	553	137	33
	1979	BDN-A_2	663	737	74	11
	Average		540	645	105	19
Coimbatore	1978	Multi	358	484	126	35
	1979	CC-1	453	521	68	15
	Average		405	503	98	24
Jabalpur	1978	JNKW-1	483	728	245	51
	1979	KA-1	577	783	206	36
	Average		530	756	226	43
Baroda	1978	F-4	1468	1656	188	13
Sardar Krishinagar	1979	F-4	771	1162	391	51
	Average		1120	1409	289	26
Ludhiana	1978	P-4	647	733	86	13
	1979	BDN-A_2	1075	1603	528	49
	Average		861	1168	307	36
Hissar	1978	PBH 8/7	1892	2107	215	11
	1979	F-4	1133	1316	183	16
	Average		1513	1712	198	13

a. Estimates based on average of 1978 and 1979.

strain. At Ludhiana and Baroda, strains F-4 and KA-1, strains PBH 8/7 and KA-1 at Hissar (Tables 6, 7) showed similar trends.

From these observations it is clear that the quality of the nodule in terms of colonization with an efficient and dominant strain of *Rhizobium,* rather than nodule number or weight, is responsible for the establishment of an efficient symbiotic relationship resulting in higher grain yield.

Rhizobium-Host Cultivar Interaction

On an overall mean basis, strains KA-1 and IHP-195 proved to be the best performers, while BDN-A2 was very poor at Gulbarga. However, when cultivar-strain interaction was taken into consideration, strain KA-1 interacted best with cvs T-21 and GS-1, whereas strain BDN-A2, which performed poorly on an overall mean basis, interacted comparable to the best with cv C-11, recording an increase of 35% as against an 8% increase with strain KA-1. At Badnapur, though the best response was obtained with strain BDN-A2 and IHP-195 on an overall mean basis, the cv T-21 responded only to BDN-Aa, whereas IHP-195 interacted best with the cv BDN-1 (Table 8). At Jabalpur, though strain JNKW-1 was the best performer and IHP-195 was fourth in the rank, strain performances with cv KH-2 showed that strain IHP-195 was 14% better than JNKVV-1, which interacted best with cv T-21 (Table 9). Similarly at Ludhiana, though on an overall basis strain F-4 was the best performer, it interacted only with cv T-21 and P8-9 while cv P4-4 responded to IHP-195 only (Table 10). Comparable trends were observed during 1979 trials also (Table 8, 9, 10). The

Table 2. Effect of *Rhizobium* inoculation on yield of pigeonpea in the peninsular zone of India.

Location	Cultivar	*Rhizobium* strain	Yield (kg/ha)		Increase over control	
			Control	Inoculated	(kg/ha)	(%)
1978						
Gulbarga	T-21.GS-1, C-11	KA-1	795	997	202	25
		IHP-195	795	966	171	22
		BDN-A2	795	792		
		F4-4	795	759		
LSD(5%)					153	
Badnapur	T-21, BDN-1	BDN-A_2	416	553	137	33
		IHP-195	416	538	122	29
		CC-1	416	489	73	18
		KA-1	416	454	38	9
		F-4	416	432	16	4
Coimbatore	CO-3	Multi	358	484	126	35
		CC-1	358	442	84	23
		IHP-195	358	440	82	23
		H-65	358	420	62	17
		F-4	358	416	58	16
		BDN-A_2	358	366	8	
LSD (5%)					36	
Kaveripattinam	CO-3	Multi	312	447	135	43
		CC-1	312	432	120	38
		IHP-195	312	419	107	34
		F-4	312	358	46	15
		BDN-A2	312	308		
LSD (5%)					64	
1979						
Coimbatore	T-21, CO-3	CC-1	453	521	68	15*
		IHP-195	453	516	63	14*
LSD (5%)					43	
Badnapur	T-21, BDN-1	BDN-A2	663	737	74	11
		IHP-195	663	721	58	9
Hyderabad	ST-1, T-21	A-3	689	907	218	31
		CC-1	689	891	202	29
		BDN-A2	689	845	156	22
		F-4	689	810	121	17
		KA-1	689	764	75	11
		TAL-190	689	745	56	8
Gulbarga	T-21,GS-1,PT-221	KA-1	1233	1320	87	7
		UASB	1233	1298	65	5
		F-4	1233	1269	36	3

Table 3. Effect of *Rhizobium* inoculation on yield of pigeon pea in the central zone of India.

Location	Cultivar	*Rhizobium* Strain	Yield (kg/ha) Control	Yield (kg/ha) Inoculated	Grain yield increase (kg/ha)	Grain yield increase (%)
1978						
Jabalpur	KH-2, T-21	JNKW-1	483	728	245	51*
		JNKW-2	483	676	193	40*
		F-4	483	638	155	32*
		IHP-195	483	597	114	24*
		Bangalore	483	582	99	20
		Nitragin	483	555	72	15
		KA-1	483	550	67	14
		CC-1	483	539	56	12
		BDN-A_2	483	497	14	3
LSD (5%)					101	
Baroda	T-21.T-15-15	F-4	1468	1656	188	13
		CC-1	1468	1575	107	7
		BDN-As	1468	1564	96	7
		IHP-195	1468	1558	90	6
		KA-1	1468	1541	73	5
1979						
Jabalpur	T-21, KH-2	KA-1	577	783	206	36*
		F-4	577	757	180	31*
		TAL-241	577	744	167	29*
LSD <5%)					75	
Sardar Krishinagar	T-21, T-15-15	F-4	771	1162	391	51
		CC-1	771	1148	377	49
		A-1-36	771	1146	375	49
		KA-1	771	960	189	24

response to inoculation further improved up to 79% over the control yields when the best interacting strain of *Rhizobium* was used with a particular cultivar of pigeonpea. The quantum of actual increase over uninoculated crop varied from 60 kg/ha to 730 kg/ha. When the mean value of 2 years is taken into consideration, the response due to inoculation varied from 13 to 43% (Table 1), with the best interacting strain, from 11 to 54% (Table 11).

Rhizobial Strain x Environmental (Location and Year) Interaction

Another point emerging from the data is the interaction between location and strain of *Rhizobium.* As might be expected, in the traditional pigeonpea-growing strains isolated locally or from other traditional areas gave the best performance. But even in nontraditional areas, different strains gave the top performance in different years, when the performance was averaged over several cultivars. At Ludhiana, strains F-4 and BDN-A2 and at Hissar PBH-8/7 and F-4 were the best performers during 1978 and 1979 respectively (Table 1). Also at the same location, the best response was obtained with different rhizobial strains when different genotypes were involved (Table 11). Interestingly enough, with the same host cultivar such as T-21, the best performing strain varied from location to location; however, such a strain was usually a strain isolated locally or from other traditional areas of pigeonpea cultivation.

Table 4. Effect of *Rhizobium* inoculation on yield of pigeonpea in the northern plains zone of India.

Location	Cultivar	*Rhizobium* strain	Yield (kg/ha)		Increase over control	
			Control	Inoculated	(kg/ha)	(%)
1978						
Ludhiana	T-21, P4-4, P8-9	F-4	647	733	86	13*
		IHP-195	647	705	58	9*
		KA-1	647	684	37	6*
LSD (5%)					35	
Hissar	T-21, UPAS-120	PBH-8/7	1892	2107	215	11
		CC-1	1892	2067	175	9
		IHP-195	1892	2015	123	6
		F-4	1892	2006	114	6
		KA-1	1892	1967	75	4
		BDN-A2	1892	1920	28	1
1979						
Ludhiana	T-21, P4-4, P8-9	BDN-A_2	1075	1603	528	49*
		IHP-195	1075	1427	352	33*
		A-1-36	1075	1361	286	27*
		F-4	1075	1293	218	20*
		KA-1	1075	1211	136	13*
LSD (5%)					122	
Hissar	Prabhat	F-4	1133	1316	183	16
		Pant	1133	1300	167	14
Varanasi	T-21, NP (WR)-15	F-4	1758	1830	72	4
		IHP-195	1758	1821	63	3

All this suggests a complex system of host genotype x rhizobial strain x environment (location x year) interaction. Further research is needed if we are to fully understand this complex system and manipulate it so that the pigeonpea crop not only meets all its own nitrogen requirement from the atmosphere, but also leaves behind for the succeeding crop a significant portion of the nitrogen fixed.

Acknowledgment

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Table 5. Effect of inoculation on nodulation in pigeonpea in the Peninsular cone of India, 1978.

Location	Cultivar	*Rhizobium* strain	Nodule no./ plant	Nodule wt/ plant (mg)	Grain yield increase (%)
Gulbarga	T-21,GS-1,C-11	KA-1	15.1	43.3	25
		IBP-195	12.9	50.3	22
		BDN-A_2	11.52	34.0	
		F-4	14.05	35.7	
		Bangalore	10.61	43.0	
Badnapur	T-21,BDN-1	BDN-A2	16.4	16.5	33
		IHP-195	15.8	15.8	29
		CC-1	15.6	20.6	18
		KA-1	14.2	14.1	9
		F-4	14.5	19.6	4
Coimbatore	CO-3	Multi	4.8	18.6	35
		CC-1	2.2	10.0	23
		IHP-195	2.8	12.4	23
		H-65	2.0	9.0	17
		F-4	3.2	14.4	16
		BDN-A_2	2.0	9.6	2
LSD (5%)			1.89	7.6	
Kaveripattinam	CO-3	Multi	4.0	32.7	43
		CC-1	3.2	26.0	38
		IHP-195	2.2	17.5	34
		F-4	1.2	9.7	15
		BDN-A_2	1.7	13.7	
LSD (5%)			0.58	7.8	

Table 6. Effect of inoculation on nodulation in pigeonpea in the central zone of India, 1978.

Location	Cultivar	*Rhizobium* strain	Nodule no./ plant	Nodule wt/ plant (mg)	Grain yield increase (%)
Jabalpur	KH-2, T-21	JNKVV-1	13.3	21.4	51*
		JNKVV-2	12.0	20.6	40*
		F-4	8.8	11.2	32*
		IHP-195	15.0	36.3	24*
		Bangalore	8.9	21.2	20
		Nitragin	8.9	18.4	15
		KA-1	7.2	14.1	14
		CC-1	12.4	21.6	12
		BDN-A2	8.4	17.8	3
LSD (5%)			0.86	1.86	
Baroda	T-21, T 15-15	F-4	8.5	40.3	13
		CC-1	8.1	36.7	7
		BDN-A_2	6.5	26.7	7
		IHP-195	8.2	36.7	6
		KA-1	10.3	36.8	5

Table 7. Effect of inoculation on nodulation in pigeonpea in the northern plains wast zona of India, 1978.

Location	Cultivar	Strain	Nodule no./ plant	Nodule wt/ plant (mg)	Grain yield increase (%)
Ludhiana	T-21,P4-4, P8-9	F-4	5.4	24.3	13
		IHP-195	4.6	23.8	9
		KA-1	5.3	23.2	6
Hissar	T-21, UPAS-120	PBH 8/7	13.8	32.5	11
		CC-1	11.7	37.1	9
		IHP-195	12.6	24.6	6
		F-4	11.4	20.6	6
		KA-1	21.7	37.1	4
		BDN-A2	11.7	20.3	1

Table 8. Interaction between *Rhizobium* strains and pigeonpea cultivars in the peninsular zone of India.

Location	Cultivar	*Rhizobium* strain	Yield (kg/ha)		Increase over control	
			Control	Inoculated	(kg/ha)	(%)
1978						
Gulbarga	T-21	KA-1	645	963	318	49*
		IHP-195	645	778	133	21
	GS-1	KA-1	1138	1377	239	21*
		IHP-195	1138	1305	167	15
	C-11	IHP-195	602	814	212	35
		BDN-A2	602	811	209	35
		KA-1	602	651	49	8
LSD (5%)					232	
Badnapur	T-21	BDN-A_2	372	547	175	47
		CC-1	372	518	139	37
		KA-1	372	401	29	8
	BDN-1	IHP-195	461	681	220	48
		KA-1	461	559	98	21
		BDN-A2	461	507	46	10
		F-4	461	503	39	8
Hyderabad	T-21	F-4	1130	1652	522	46
		CC-1	1130	1388	258	23
1979						
Coimbatore	T-21	CC-1	425	522	97	23*
		IHP-195	425	518	93	22*
		F-4	425	480	55	13*
		BDN-A2	425	476	51	12*
	CO-3	CC-1	480	519	39	8
		IHP-195	480	514	34	7
LSD(5%)					43	

Continued

Table 8. *Continued*

Location	Cultivar	*Rhizobium* strain	Yield (kg/ha)		Increase over control	
			Control	Inoculated	(kg/ha)	(%)
Badnapur	T-21	BDN-A_2	529	775	246	46
		CC-1	529	740	211	40
		F-4	529	687	158	30
		KA-1	529	658	129	24
		IHP-195	529	582	53	10
	BDN-1	IHP-195	796	859	63	8
Hyderabad	T-21	A-3	745	990	245	33
		F-4	745	962	217	29
		CC-1	745	938	195	26
		BDN-A2	745	924	179	24
		KA-1	745	899	154	20
	LRG-30	TAL-190	680	792	112	16
		A-3	680	787	107	15
	ST-1	CC-1	644	1110	466	72
		BDN-A2	644	976	332	51
		A-3	644	945	301	46
		KA-1	644	939	295	45
		F-4	644	777	133	20
		TAL-190	644	770	126	19
Gulbarga	T-21	KA-1	403	647	244	60
	GS-1	USAB	1720	1788	66	4
	PT-22	USAB	1577	1750	173	11
		F-4	1577	1696	119	7

Table 9. Interaction between *Rhizobium* strains and pigeonpea cultivars in the central zone of India.

Location	Cultivar	*Rhizobium* strain	Yield (kg/ha)		Grain yield increase	
			Control	Inoculated	(kg/ha)	(%)
1978						
Jabalpur	KH-2	IHP-195	485	732	247	50*
		JNKW-2	485	725	240	50*
		JNKVV-1	485	760	175	36*
		CC-1	485	590	105	22
		F-4	485	583	98	20
	T-21	JNKVV-1	482	797	315	65*
		F-4	482	693	211	44*
		JNKW-2	482	627	145	30*
		Bangalore	482	597	115	24
		KA-1	482	593	111	23
LSD (5%)					142	

Continued

Table 9. *Continued*

Location	Cultivar	*Rhizobium* strain	Yield (kg/ha)		Grain yield increase	
			Control	Inoculated	(kg/ha)	(%)
Baroda	T-21	F-4	1476	1789	313	21
		CC-1	1476	1700	224	15
		IHP-195	1476	1667	191	13
		BDN-As	1476	1619	143	10
		KA-1	1476	1457		
	T-15-15	KA-1	1461	1626	165	11
		F-4	1461	1524	63	4
		BDN-A2	1461	1510	49	3
		CC-1	1461	1451		
		IHP-195	1461	1450		
1979						
Jabalpur	KH-2	KA-1	612	897	285	46*
		TAL-241	612	852	240	39*
		CC-1	612	798	186	30*
		BDN-A_2	612	747	135	22*
		F-4	612	733	121	19*
		AR-111	612	717	105	17
		JN-1	612	717	105	17
	T-21	F-4	543	780	237	43*
		AR-111	543	738	195	36*
		JN-2	543	735	192	35*
		KA-1	543	670	127	23*
		CC-1	543	658	115	21*
		IHP-195	543	645	102	18
LSD (5%)					106	
Sardar Krishinagar	T-21	KA-1	617	818	201	32
		A-1-36	617	772	155	25
		CC-1	617	728	111	18
		BDN-A2	617	90	73	12
		F-4	617	17	50	8
	T-15-15	F-4	925	1656	731	79
		CC-1	925	1567	642	69
		A-1-36	925	1520	595	64
		KA-1	925	1101	176	19

Table 10. Interaction between *Rhizobium* strains and pigeonpaa cultivars in the northern plains west zone of India.

Location	Cultivar	*Rhizobium* strain	Yield (kg/ha) Control	Yield (kg/ha) Inoculated	Grain yield increase (kg/ha)	Grain yield increase (%)
1978						
Ludhiana	T-21	F-4	621	749	128	21
		KA-1	621	649	28	5
		IHP-195	621	629	08	
	P4-4	IHP-195	644	802	158	25
	P8-9	F-4	677	832	155	23
		KA-1	677	787	110	16
		IHP-195	677	683	6	
LSD (5%)					61	
Hissar	T-21	PHB-8/7	1800	2095	295	16
		IHP-195	1800	2015	215	12
		CC-1	1800	1965	165	9
	UPAS-120	F-4	1985	2187	202	10
		CC-1	1985	2170	185	9
		PBH-8/7	1985	2120	135	7
1979						
Ludhiana	T-21	BDN-A_2	1171	1916	745	63*
		IHP-195	1171	1710	539	46*
		A-1-36	1171	1635	464	40*
		F-4	1171	1572	401	34*
		KA-1	1171	1406	235	20*
	P4-4	IHP-195	960	1610	650	67*
		BDN-A_2	960	1560	600	62*
		K-1-38	960	1543	583	60*
		KA-1	960	1341	381	40*
		F-4	960	1205	245	25*
	P8-9	BDN-A2	1093	1340	247	22*
LSD (5%)					211	

Table 11. Performance of pigeonpea cultivars with best interacting rhizobial strain.

location Year	Cultivar	*Rhiaobium* Strain	Yield (kg/ha) Control	Yield (kg/ha) Inoculated	Increase over control (kg/ha)	Increase over control (%)
Gulbarga						
1978	T-21	KA-1	645	963	313	49
1979	T-21	KA-1	403	647	244	60
Average			524	805	281	54
1978	GS-1	KA-1	1138	1377	239	21
1979	GS-1	UASB	1720	1788	66	4
Average			1429	1580	154	11
Badnapur						
1978	T-21	BDN-A2	372	547	175	47
1979	T-21	BDN-A2	529	775	246	46
Average			451	661	210	46
1978	BDN-1	IHP-195	461	681	220	48
1979	BDN-1	IHP-195	796	859	63	8
Average			629	770	141	22
Hyderabad						
1978	T-21	F-4	1130	1652	522	46
1979	T-21	F-4	745	962	217	29
Average			938	1307	369	39
Coimbatore						
1973	CO-3	Multi	358	484	126	35
1979	CO-3	CC-1	480	519	39	8
Average			419	502	83	20
Jabalpur						
1978	KH-2	IHP-195	485	732	247	50
1979	KH-2	KA-1	612	897	285	46
Average			549	615	266	48
1978	T-21	JNKW-1	482	797	315	65
1979	T-21	F-4	543	780	237	43
Average			513	789	276	54
Baroda and Sardar Krishinagar						
1978	T-21	F-4	1476	1789	313	21
1979	T-21	KA-1	617	818	201	32
Average			1047	1304	257	25
1978	T-15-15	KA-1	1461	1626	165	11
1979	T-15-15	F-4	925	1656	731	79
Average			1193	1641	448	38
Ludhiana						
1978	T-21	F-4	621	749	128	21
1979	T-21	BDN-A2	1171	1916	745	63
Average			896	1333	437	49
1978	P4-4	IHP-195	644	802	158	25
1979	P4-4	IHP-195	960	1610	650	67
Average			802	1206	404	50
1978	P8-9	F-4	677	832	155	23
1979	P8-9	BDN-A2	1093	1340	247	22
Average			885	1086	201	23

a. Estimates based on average performance of cultivars In 1978 and 1979.

Measurement of Inoculation Response in Pigeonpea

J. A. Thompson, J. V. D. K. Kumar Rao, and P. J. Dart*

Abstract

A brief description of nodule development in ICRISAT soils is presented. An examination is then made of the information gained from 12 field experiments investigating inoculation responses by different strains of rhizobia. The relationship of the various criteria measured, the problems of making measurements, and some possible alternatives are discussed. The discussion is developed in relation to the potential of techniques available for study of Rhizobium *ecology, the value of inoculant responses, and the significance of standards of inocula currently available in India.*

Nodule Development

Nodule formation in pigeonpea is initiated through infection thread development in the root hairs. Unlike freely nodulating plants such as groundnut, where nodules arise in the axil of a lateral root, pigeonpea has a comparatively low intensity of nodulation per unit of root length, much less than for *Vigna* spp. when grown under the same conditions. Pigeonpea nodules have a terminal meristem and, as in cowpea, a green-pigmented, senescent zone develops from the base of the nodule. The bacteroid zone of pigeonpea nodules may be pink, because leghemoglobin is present, but may also be brown; it is not known if the brown nodules are less active in nitrogen fixation. In some strain-cultivar combinations, a deep purple to black pigment colors the bacteroid zone. Occasionally, several nodules form close together on lateral roots.

Nodule formation and development are affected by soil type, season, and duration of the cultivar. Nodulation in pigeonpea is rapid, with about 25 nodules per plant formed in an Alfisol by 15 days after sowing, with about half on the primary root. These nodules on the primary root usually have a short lifespan (< 60 days). Nodules continue to form up to 120days in both Alfisols and Vertisols, but senescence and nodule predation by a Dipteran larva, *Rivellia angulata* Hendel (Sithanantham et al. these Proceedings; Siddappaji and Gowda, 1980), result in a loss of active nodules, particularly in Vertisols, starting from about 30 days after planting and increasing as the plant ages. Most nodules are formed on the secondary roots and extend to a 1 m depth. In general, more than twice as many nodules of greater weight are found during the rainy season in the Alfisol than in the Vertisol (Table 1), but after the rains cease, nodule formation in the Vertisol is greater. In a 1976 sowing there were 136 nodules per plant in the Alfisol and 200 in the Vertisol after 120 days, but only 15% and 2% of these were active. When plants are sown in the postrainy season, few nodules are formed, presumably because of lower moisture availability and low temperatures (Table 1). Further, pigeonpea nodulation is found to be affected by the crop duration. Early cultivars (about 120 days at Hyderabad) have fewer nodules compared with medium- (about 150 days) and late-maturing (about 200 days) cultivars (Table 2).

There is variability between germplasm lines in nodulation and associated criteria. Table 3 shows large differences in the numbers of nodules formed and nodule weight on 25-day-old plants. It is not known whether the relative nodulating frequencies observed in the seedling state persist in later plant development.

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Table 1. Nodulation of pigeonpea cv ICP-1 sown in rainy and postrainy seasons at ICRISAT Center.

Season	Days after sowing					
	30	60	120	30	60	120
Rainy season	Nodule no./plant			Nodule dry wt./ plant (mg)		
Alfisol	39	64	134	79	521	293
Vertisol	29	25	200	52	87	ND[a]
Postrainy season						
Vertisol	12	9	7	9	52	35

a. All nodules damaged and not recoverable.

Table 2. Nodulation of pigeon pea of different maturity groups grown in an Alfisol during 1977 rainy season.

Maturity group	Days after sowing					
	20	40	60	80	100	140
	Nodule no./plant					
Early	12	14	21	50	21	
Medium	16	24	32	118	60	75
Late	12	17	22	76	70	78

Table 3. Range of symbiotic characteristics in 110 pigeonpea lines, 25 days after planting in rainy season, 1977, in an Alfisol at ICRISAT.

Character	Range
Nodule number	6.7-37.8
Nodule weight (mg/plant)	9-55
Nitrogenase activity	
μmol C_2H_4/plant/hr	1.1-11.3
μ mol C_2H_4/g nodule/hr	65-565
Shoot/plant (mg)	383-1408
Root/plant (mg)	38-185

Field Measurements

Between 1976 and 1980 twelve experiments were conducted on ICRISAT fields to examine the response of pigeonpea to inoculation with selected strains of rhizobia. These strains had been selected on the basis of previous superior performance in soil or sterile sand culture under glasshouse conditions. The data examined direct measurements of field-grown material, although other derived criteria were also examined.

Of the 12 experiments, only two increased grain yield significantly, while a further two showed significant response in attributes measured early in the life of the plant (Table 4).

The two experiments showing grain yield responses were sown in different parts of the same Vertisol field in consecutive years. A concurrent study, also *on* the same field and harvested in 1980, clearly demonstrated a marked residual effect of well-grown pigeonpea on a subsequent crop of maize, illustrating that the soil was sufficiently low in nitrogen to support substantial fixation of nitrogen. However, the populations of native cowpea rhizobia in this field were 2.1 x 10^4/g soil in 1978-79 and 3.7 x 10^5/g soil in 1979-80. In the inoculation trials, 12 strains were compared with the uninoculated control in 1978-79 and 15 strains in 1979-80. Even when significant grain yield responses were measured, no correlations were found between grain yield and criteria measured early in the life of the plant for the 1978-79 trial, and few for the 1979-80 trial (Table 5). In fact, in 1979-80, the shoot dry weight at 40 days was inversely related to grain yield ($r = .615$, $p<0.05$). In terms of grain yield, the seven strains common to both experiments did not perform consistently between years (Table 6). There was no correlation of the ranking for yield between seasons, and none of these seven strains was significantly superior to the uninoculated control in both years.

Criteria of Measurement

There are limitations to the successful use and interpretation of the relatively simple criteria used in these studies to measure response to inoculation. Clearly, it is difficult to generalize and equally difficult to select a period for sampling when the interplay of the relevant factors allows best differentiation of treatments in terms of nodulation, early vegetative growth, or nitrogenase activity. This is illustrated by the fact that, although in the 2 years studied here, moisture availability to 100 days was greater in 1978-79 than 1979-80, correlations between early and late measurements were superior during the drier year. It is possible that heavy

Table 4. Incidence of significant reap on sea to inoculation of pigeon pea in field experiments.

Year	Field No.	Days after sowing	During vegetative stage: Nodule no./ plant	Nodule wt/ plant	Nitrogenase/ plant	Shoot wt/ plant	At grain harvest: Shoot wt/ ha	Grain/ ha
1976	1	15,40,60	-	-		-		-
	2	45	+[a]		-	+[b]		
		24,85	-		-	-		-
7977	3	20,60	-	-	-	-		-
	4	25,60	-	-	-	-	-	
1978	5	32	-	_	-			-
	6	31	-	-	+[c]	-		+[d]
	7	30	-	+[a]	+[f]	-		-
	8	30	-	-	-	-		-
1979	6	40	_	-	-	-	+[g]	+[h]
	9	60	-	-	-	-		
	9	60	-	-		-	- -	
	10	40	-	-	-	-	-	

a 3/4 strains (nodules on secondary roots)
b. 1/4 strains
c. 1/15 strains (nitrogenase activity of nodule^{-1})
d. 1/4 strains
a. 1/5 strains
f. 1/5 strains
g 5/12 strains
h. 4/12 strains

Table 5. Correlations(r) between criteria measured in inoculation experiments on a Vertisol field at ICRISAT in consecutive years.

	30 days after sowing			At grain harvest	
1978-79	Nodule wt/ plant	Nitrogenase/ plant	Shoot wt/ plant	Plant wt/ha	Grain wt/ha
Nodule no./plant	.411	.300	.053		-.063
Nodule wt/plant	1	-.092	.480		-.233
Nitrogenase/plant		1	.208		.339
Shoot wt/plant			1		.437
1979-80	40 days after sowing			At grain harvest	
Nodule no./plant	.813*	.345	-.473	-.232	.603*
Nodule wt/plant	1	.713*	-.409	.166	.327
Nitrogenase/plant		1	.073	-.383	-.298
Shoot wt/plant			1	-.445	-.615*
Harvest total wt/ha				1	.960***

*Correlation significant (P<0.05) ***Correlation significant (P<0.001)

rains in late September of 1979 may have caused a flush of new nodules and thus contributed to the superiority of some strains.

Part of the difficulty of selecting suitable sampling dates for nodule evaluation is bound up with the physical difficulty of, and time involved in, digging and recovering nodules, especially with older plants under the normal conditions of declining moisture. For these reasons the reports of lack of nodulation must be treated with caution.

We have emphasized here the importance of

Table 6. **Relationship between grain yields (kg/ha) of pigeonpea inoculated with seven *Rhizoblum* strains in consecutive years on the same field.**

	1978-79	1979-80
IHP 35	1750*	1440
IHP 147	1720*	1700
IHP 71	1680*	1530
IHP 195	1590*	1630
IHP 24	1560	1640
IHP 100	1540	1830*
IHP 229	1340	1520
Uninoculated	1370	1430

* Significantly superior to noninoculated control ($p<0.05$). (Correlation between years $r = 0.17$)

the grain yield essentially as an integration of all nitrogen inputs. However, apart from the risk common to all crops under a declining moisture regime — the risk that early nitrogen responses will fail to be reflected in grain yield because of induced moisture stress with early vigorous growth — pigeonpea has a low harvest index. The amount of vegetative material can exceed the grain yield; additionally in India, the stem material has economic value as fuel and fallen leaf accounts for up to 25% of total dry matter; with a nitrogen content of 1.5%, an important part of the plant's nitrogen is not available for translocation to the grain. Not only should this material be included in any measurement of dry matter or nitrogen yield, but measurements of total vegetative yield may in fact constitute a more realistic measurement of nitrogen-fixation than grain yield.

It is possible that indirect measurement of N return to the soil, by use of a nonlegume in the subsequent season, may be a useful criterion of evaluation of nodulation responses. It is costly in relation to time and land, but may be economical in terms of labor resources, if it replaces the intensive measurement associated with excavation of plants.

We are left at this point with a number of questions that can only be resolved by better understanding of the factors affecting nodule formation and function. The major limitation of acetylene reduction as a means of measuring nitrogenase activity is that it is a "spot" test and not really integrative. It is also destructive of field material. We do not yet know whether the ureide estimation (Kumar Rao et al. these Proceedings) will eventually be a spot test or an integrated measure, nor do we know whether it needs to be destructive of the whole plant.

Meanwhile, the most pressing question in relation to inoculation is the need to understand the ecology of both the inoculant and the native rhizobia.

Significance of Ecological Studies

Serological and genetic marking (i.e. antibiotic-resistant mutants) can enable us to identify the known inoculant strains that have formed the nodules, but we remain ignorant of the composition of the native microflora. A recently developed technique, currently in use at ICRISAT with chickpea rhizobia, shows considerable promise in differentiating between native strains. The technique (Beynon and Josey 1980) depends on differential inherent resistance of *Rhizobium* isolates to very low antibiotic concentrations. By this means, we expect to be able to characterize the native populations forming nodules and determine how these populations change between years and seasons. In turn, this may go a long way towards explaining the year-to-year differences so common in such studies with all legumes, and illustrated so graphically in Table 6.

Inoculant Quality

While we must accept that the magnitude of the yield responses shown in Table 6 is in part due to effective insect control reducing grain losses in an experimental situation, the benefits remain considerable. At 1979 prices (Rs. 2.65/kg grain; Rs. 2.00/packet inoculum), the best stra ins returned upwa rds of Rs. 1000/ha at a cost of a few rupees. Even a success rate of 2 out of 12 makes this economic.

The evidence of responses in two experiments suggests that the successful strains were adequately represented on the seed in the two successful sowings. At least 10^4 rhizobia/seed were applied in these sowings. This, however, raises a particular point of concern. While high

Table 7. Rhizobia in plgeonpea inocula sold in India during 1978-80.

Source	Plate count (No./g inoculum)	Plant count (No./g inoculum)	No. seed (based on plant count)
A	3.4×10^{7}	$<2.3 \times 10^{4}$	<6
B	8.8×10^{7}	9.2×10^{4}	26
C	2.4×10^{7}	1.5×10^{6}	420
D	1.4×10^{7}	4.2×10^{4}	12
E	2.3×10^{7}	2.3×10^{6}	650
F	2.4×10^{8}	$<2.3 \times 10^{4}$	<6
G	–	1.5×10^{5}	42
H1	3.0×10^{8}	4.6×10^{5}	1300
H2	3.9×10^{8}	6×10^{4}	17
I	2.5×10^{8}	$<2 \times 10^{2}$	<0.1
J	2.3×10^{7}	1.5×10^{4}	4
K	1.2x 10»	2.4×10^{9}	670 000
Geometric mean	7.5×10^{7}	1.9×10^{5}	

levels of inocula per se cannot be expected to produce responses, low levels have much less chance. The soil populations in these studies were above 10^4/g in both years. These levels are relatively high, and a competitive inoculum must also be of high numerical quality. Over many years, minimal inoculum figures have been discussed by many authors and are governed by the level of the soil population. However, figures of the order of 100 to 1000 per seed are at the lower end of the scales proposed. It is important to examine the data in Table 7 in relation to two significant points:

1. Over a wide range of Indian inocula, the commonly used plate count, which depends on visual recognition of colonies on agar, greatly overestimated numbers compared with the plant infection dilution count, which depends on nodule formation for estimation. The overestimate here averaged 400-fold.

2. The numbers of rhizobia recovered from inoculants in India are frequently low, in spite of the fact that production is largely under the control of agricultural universities and other official institutions, as advocated by Subba Rao (1972). Based on the plant infection test, only one of the 12 batches tested during 1978-80 passed the Indian Standards Institution standard requiring at least 10^7 viable rhizobia per g carrier (Indian Standards Institution 1977).

Clearly, we can only capitalize on superior or more reliable techniques of measurement of inoculant response if the inocula available provide adequate numbers to be likely to form nodules.

Acknowledgment

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References

BEYNON.J. L.,and JOSEY,D.P. 1980. Demonstration of heterogeneity in a natural population of *Rhizobium phaseoli* using variation in intrinsic antibiotic resistance. Journal of General Microbiology 118: 437-442.

INDIAN STANDARDS INSTITUTION. 1977. Indian standard specification for *Rhizobium* inoculants. New Delhi, India: ISI.

SIDDAPPAJI, C, and GOWDA, T. K. S. 1980. Rhizobial nodules eating insect —*Rivellia* sp. — a new pest of pulse crops in India. Current Science 9: 122-123.

SUBBA RAO, N. S. 1972. A case for production of bacterial fertilizers in India. Fertilizer News 17: 37-43.

Discussion—Session 6

Velayutham:

1. Under the coordinated soil test/crop response project of the ICAR, the establishment of critical limits of soil nutrients indicates that 20 kg/ha Olsen's P is the limit in the medium to deep black soils (Vertisols) of Madhya Pradesh.

2. Definition of soil fertility parameters is emphasized for meaningful interpretation of fertilizer experiments.

Edwards:

I am in complete agreement with your comments; however, I would emphasize the importance of calibrating your yield response against the soil-test value in your experimental treatments. This will further add to your body of useful information. In all other field experiments, no matter what their objective, soil fertility status should be defined as far as possible.

Parpia:

In studying micronutrient requirements of plants, there is an urgent need to consider development of varieties that would provide adequate human nutritional needs of minerals, especially iron, zinc, and manganese, as these nutrients when provided as a part of the natural food are much better absorbed than when they are administered as artificial supplements. Iron deficiency in diets is a serious problem in the tropics. How much attention have the nutritionists and breeders given tothis important problem?

Katyal:

Studies on micronutrient contents of foods and human health are exceedingly important. I cite the example of zinc deficiency leading to dwarfism, sex disorders, and other abnormalities among some people whose diet mainly consists of unleavened bread. Similarly, people living away from the sea, particularly in the mountains, suffer from goiter dueto insufficiency of iodine in their diet, because the soils of these regions are low in iodine. Nonetheless, with the majority of the micronutrients, such association is vitiated, since food often comes from geographic locations other than the area where it is consumed. Cooking vessels also enrich the food with the metals of their construction.

Micronutrient levels in soils are more closely related to animal health than to human health.

De:

I do not agree that molybdenum requirement for nodulation and plant growth cannot be separated from each other. With the aid of proper experimental design, it should be possible to differentiate between the molybdenum requirement for nodule formation and the requirement for plant growth per se. At least *Rhizobium-iree* growth of pigeonpea should be easy to do.

Katyal:

Any attempt to isolate the effect of molybdenum on plant growth and rhizobia yields the following:

1. If plants are cultivated in molybdenum-deficient conditions, their growth is poor, with a concomitant adverse effect on *Rhizobium* growth and nitrogen fixation.

2. If molybdenum deficiency is eliminated, plants are healthy, and there is a simultaneous increase in nitrogenase activity. Furthermore, molybdenum content of seeds at times has been shown to be adequate for normal plant and *Rhizobium* growth. Thus it is not possible to separate the effect of molybdenum on plant growth and on *Rhizobium* in isolation.

Roy Sharma:

Study on the effect of organic matter was initiated in the early decades of this century at Pusa in Bihar, and the crop responded to the application of farmyard manure.

Foliar spray of 9 kg N (urea) in two sprays has increased the yield of the crop 200 to 300 kg/ha at Rajendra Agricultural University.

At Jabalpur, 50 kg (DAP) diammonium phosphate (soil) + 25 kg DAP foliar (in two sprays) have been better than 100 kg DAP applied to soil.

Panwar:

Farmers in central and eastern U.P. have long practiced the application of farmyard manure to long-duration pigeonpea varieties. The soil in these regions is poor in organic matter and long-duration pigeonpea benefits most from FYM.

The response of foliar sprays of urea at low rates, as you indicated, has been observed at several centers where DAP foliar spray has given higher yields. It is now clear that the nitrogen component, not the phosporus component, of DAP is responsible for the higher yields. At the flowering and podding stage, nitrogen fixation through nodules ceases, but the plants probably need more nitrogen for the reproductive phase. Foliar spray of nitrogen at this stage thus immediately benefits grain development.

The results obtained at Jabalpur indicate that the response was to a lower dose of phosphorus. The higher yields are probably due to the beneficial effect of nitrogen spray at the reproductive phase.

Shah:

We have heard about symptoms of various micronutrient deficiencies in pigeonpea. Are there any toxic effects from excess of any micronutrients, especially on nitrogen-fixing ability?

Edwards:

Approximately 50% of the total land mass between the Tropic of Cancer and the Tropic of Capricorn is covered by acid soils. Included among the possible limitations to plant growth on these soils are aluminum toxicity and manganese toxicity. Aluminum toxicity would appear to be a more important limitation to growth of nodulated legumes, including pigeonpea, on many of these soils. Manganese toxicity is probably somewhat less important. Although reports vary, our own work in Brisbane with *Stylosanthes* species has clearly shown that the nodulation process itself is much more sensitive to aluminum than to host-plant growth, *Rhizobium* survival, or nitrogen fixation by existing nodules. Such studies have not been done with pigeonpea.

Wallis:

Do you believe that with the wide diversity of production systems, including high-density sowing of late and photoinsensitive cultivars, that fertilizer responses in this crop will remain unimportant?

Kulkarni:

Pigeonpea yields without fertilizers are low, ranging from about 300 kg to 670 kg/ha. But the response to fertilizers when applied in balanced form is quite encouraging and has ranged from 300 kg to about 1000 to 1400 kg/ha. This means that fertilizer application is definitely paying, especially with short-duration varieties like HY-3. This is borne out by a large number of experiments both at research stations and on farmers' fields. The only difference is that at research stations the base yields are higher than on farmers' fields, because of management differences. Otherwise fertilizer responses are quite consistent and comparable under both the situations.

Avadhani:

Has Dr. Rewari studied the soil pH, nature of carrier, and soil type, since rhizobial activity is affected by these factors?

Rewari:

Soil pH, carrier, and soil type are among the important factors that influence the establishment of an efficient symbiotic system. But the trials reported were carried out to assess the performance of the available inoculants under different agroclimatic conditions to identify materials for use in the respective areas. Though pH is normally recorded, the values were not considered in this study.

C. L. L. Gowda:

As a plant breeder, I find it difficult to get a yield advantage of 20 to 25% over the local check. But your data on inoculation show up to 65% yield increase in different locations. If the responses were so convincing, why has the practice not been recommended by AICPIP after 4years of rigorous testing?

Rewari:

The results of the trials conducted under AICPIP over the years have shown definite increase in the yields of pigeonpea, varying from 10 to 60%, depending upon the area where the crop is grown. Based on this, the AICPIP has already made the recommendation for inoculation of pulses as one of the inputs to improve yields. On the basis of this recommendation, the Ministry of Agriculture, Government of India, has already set up some laboratories for mass manufacture of culture. *Rhizobium* inoculants are distributed to the farmers through the state Departments of Agriculture.

Session 7

Soils and Water

Chairman: S. M. Miranda

Rapporteur: N. P. Saxena

Pigeonpea and Its Climatic Environment

S. J. Reddy and S. M. Virmani*

Abstract

Pigeonpea is mainly grown in India in regions lying between approximately 14 and 28°N latitude. In this zone the mean temperatures vary from 26 to 30° C in the rainy season and 17to22°Cin the postrainy season. The amount of daily global solar radiation varies from 400 to 430 callcm^2 per day during the rainy season and 380 to 430 callcm^2 per day in the postrainy season. Mean annual rainfall ranges between 600 and 1400 mm, 80 to 90% of which is received during the rainy season. The majority of the principal pigeonpea-growing areas in India are endowed with a dependable and high rainfall. The length of the growing season extends from 120 to 180 days. Waterlogging is a major problem in these regions in deep Vertisols. Based on the climatic characteristics of the pigeonpea-growing areas of India, isoclimes of areas of five West African countries that are likely to provide a suitable growing environment for pigeonpea are identified.

Pigeonpea (*Cajanus cajan*) is a crop predominantly grown in tropical areas. It is cultivated in semi-arid areas of India and Kenya, and in subhumid regions of Uganda, the West Indies, Burma, and the Caribbean region. About 90% of the world production of pigeonpea is contributed by India, where pigeonpea is the most widely grown grain legume, next to chickpea. In view of its economic importance, it is essential to evaluate the agricultural climate of the pigeonpea-growing areas of India. An attempt has been made to demarcate the semi-arid region of West Africa where the crop is likely to be successful.

Areas Growing Pigeonpea in India

Based on area and production of pigeonpea, Easter and Abel (1973) demarcated 73 districts, lying between 14 and 28° N latitude, as pigeonpea-growing areas (Fig. 1). Together, they contributed about 80% to total national production during the survey period, 1967-1969. These 73 were further classed into "core" and "satellite" districts. A core district was one that had at least 5% of total cropped area under pigeonpea and contributed at least 1% to total national production during the survey period. A satellite district was one that had less than 5% but at least 2% of gross cropped area under pigeonpea and produced at least 0.5% of the national total.

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Agricultural Subdivisions of the Pigeonpea-growing Areas

The National Bureau of Soil Survey and Land Use Planning has divided India into agroecological regions based on climatic and ecological conditions (Murthy and Pandey 1978). The pigeonpea-growing areas (Fig. 2) broadly fall into three subdivisions: agricultural subdivision I, comprised of parts of Uttar Pradesh and Bihar; agricultural subdivision II, comprising primarily the western parts of Madhya Pradesh; and agricultural subdivision III, comprised of parts of Maharashtra and northern Karnataka and Andhra Pradesh. We have divided subdivision III into two further subdivisions: IIia, the rainshadow areas of the Western Ghats, having undependable southwest seasonal rainfall, and IIIb, the area lying outside the rainshadow and having relatively dependable rainfall during the rainy season.

We will use these subdivisions in discussing the soils and climate of the pigeonpea-growing areas.

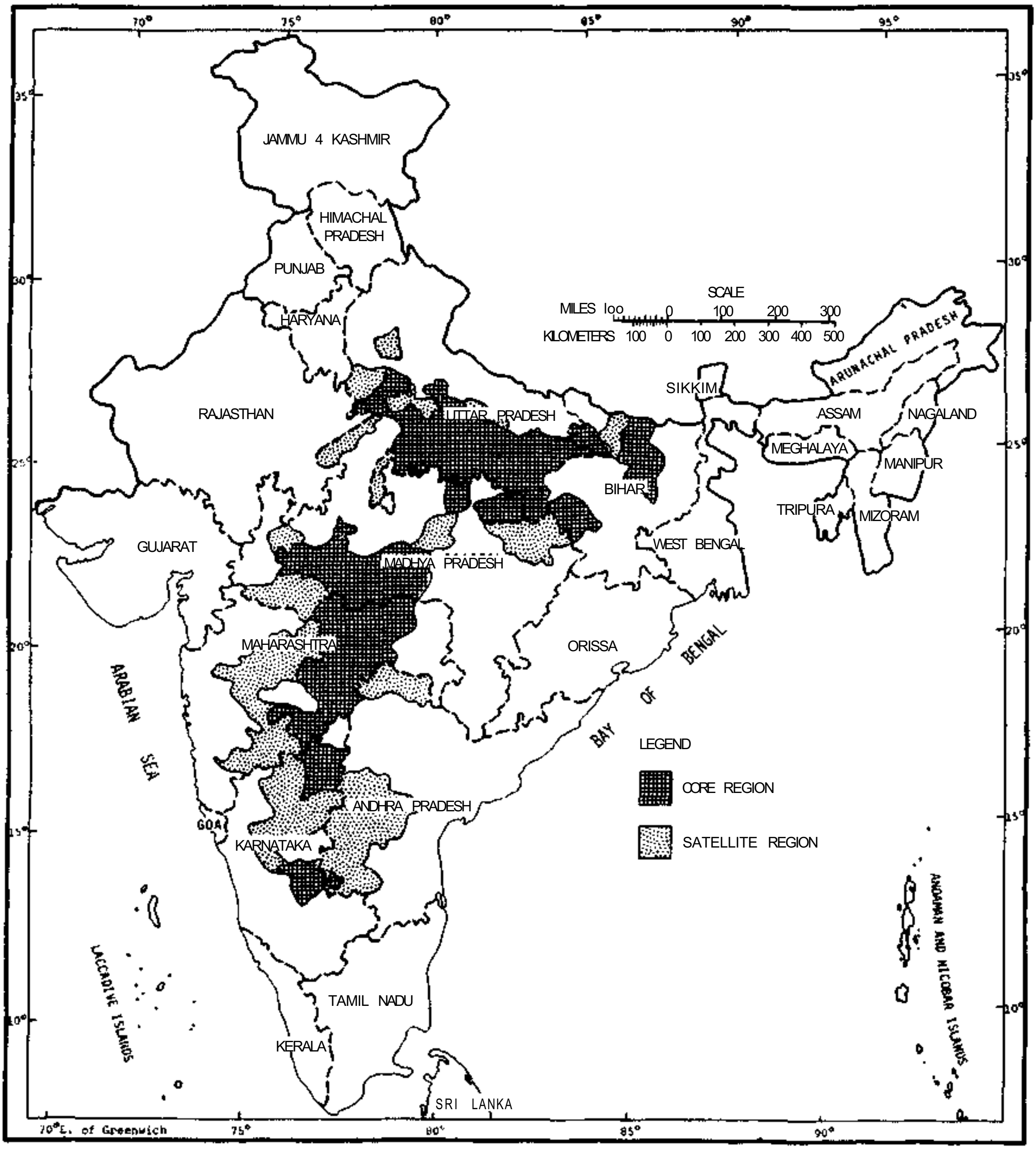

Figure 1. Pigeonpea-growing regions of India.

Soils of the Pigeonpea-growing Areas

A super-imposition of the soil map of India prepared by Murthy and Pandey (1978) over Figure 1 shows that pigeonpea is grown primarily on two soil types: (a) the Entisols, comprising the alluvial soil belt of the Indo-Gangetic region of agricultural subdivision I, and (b) the Vertisols, comprising agricultural subdivisions II and III (Fig. 3). The crop is usually grown on deep Vertisols (> 90 cm deep). A small area under pigeonpea is on Alfisols in southern Karnataka and Andhra Pradesh and eastern Madhya Pradesh.

The Entisols are deep loams, slightly alkaline

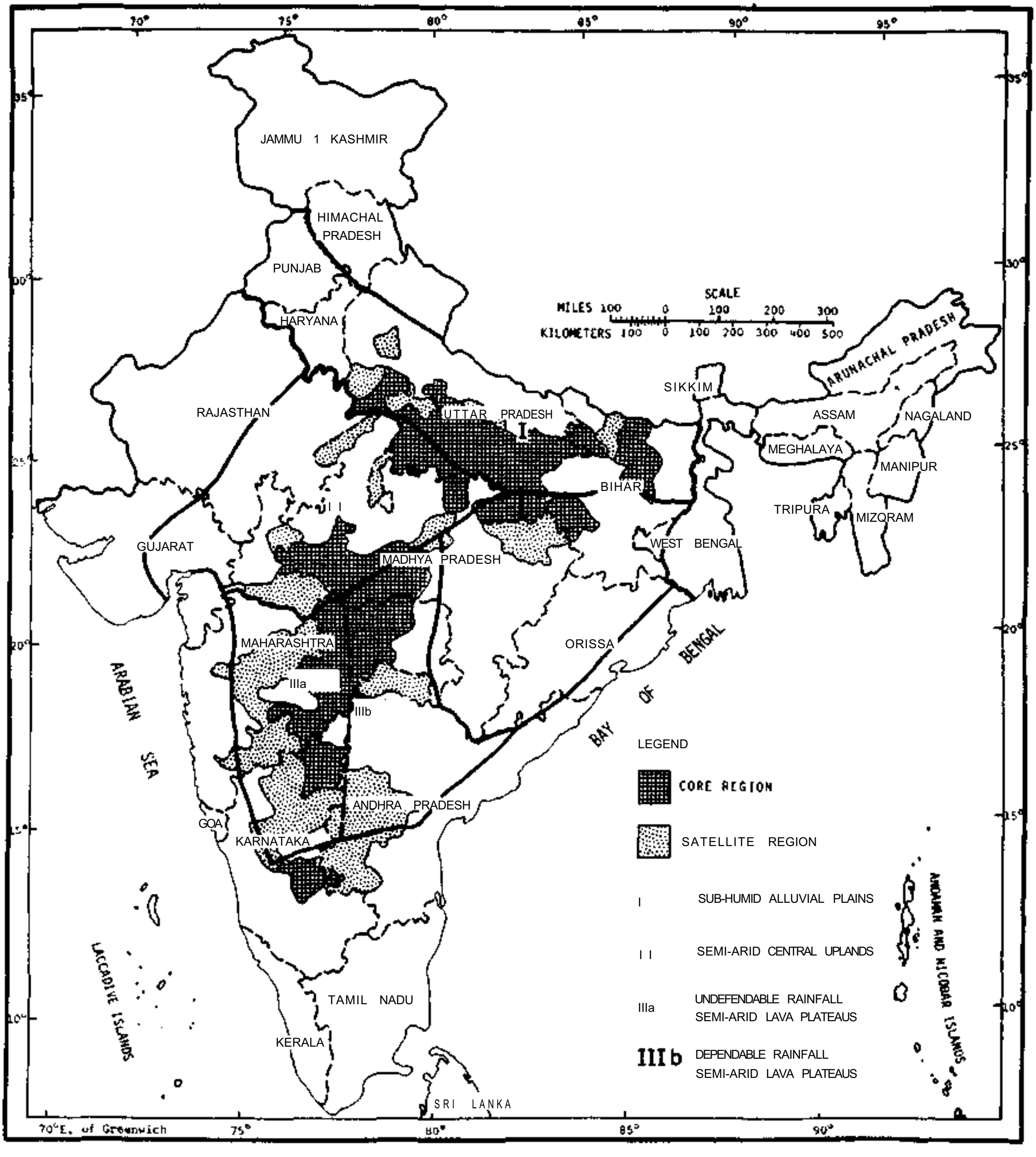

Figure 2. Agricultural subdivisions of pigeonpea regions of India.

(pH 7.5-8.5), with about 150 to 200 mm available water storage capacity in the 2-m soil depth. The Vertisols are characterized by 40 to 60% clay in the surface soil horizons, pH about 8, and can store between 150 and 300 mm available water in 1.5 to 2m soil depth. The Alfisols are usually neutral in reaction (pH 6.5-7.0), are relatively shallow (50 cm or so deep) and have less clay content. These soils are usually sandy loam in texture and can retain about 100 mm available water in the root profile at the maximum.

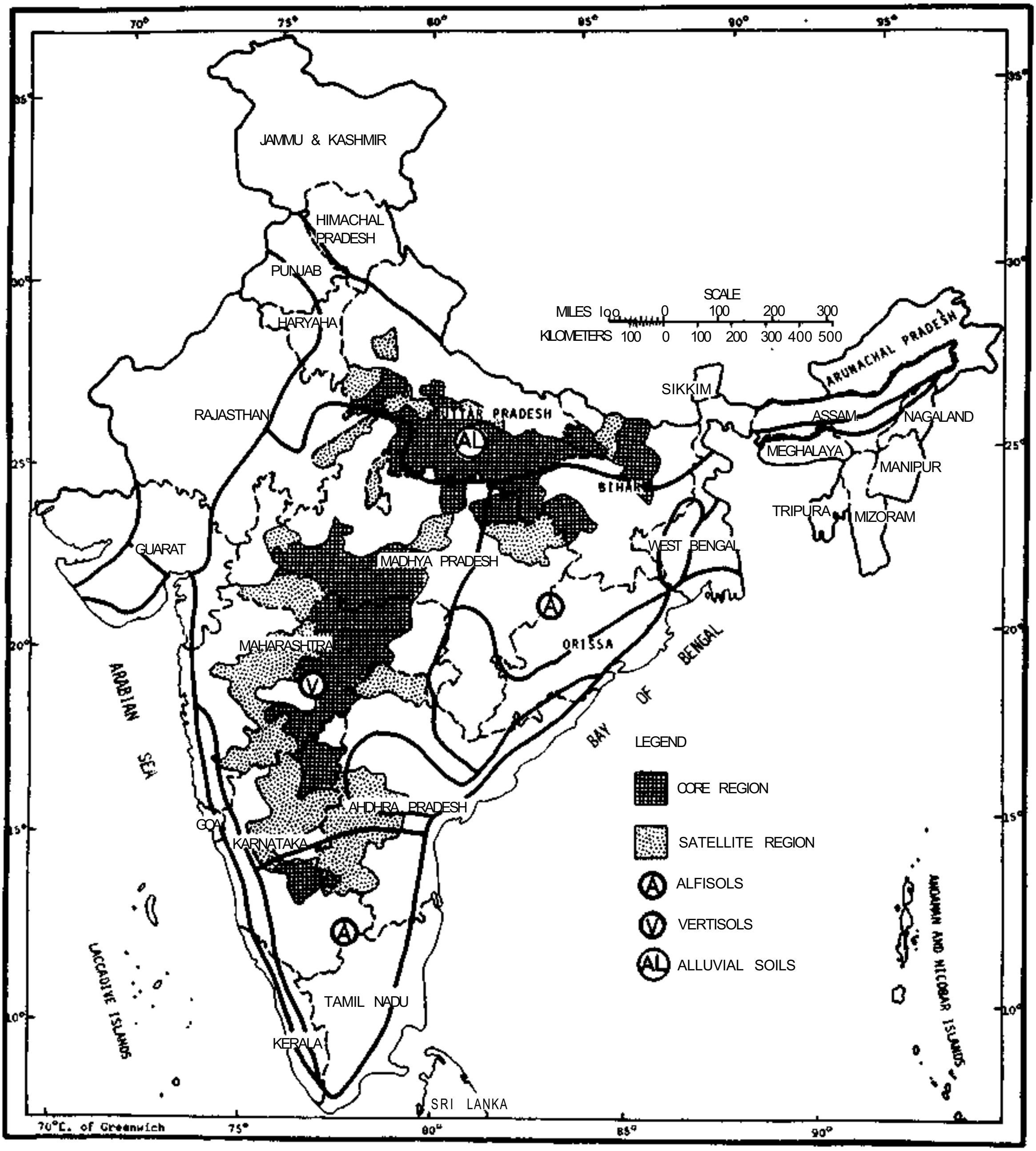

Figure 3. Predominant soil types in pigeonpea-growing regions of India.

Agroclimatic Characteristics of the Pigeonpea-growing Areas in India

In order to characterize the agroclimate, 18 districts (Table 1) were selected for detailed analysis. These vary in latitudefrom 14to 28°N; in longitude from 74 to 83° E; and in elevation from 77 to 733 m above the mean sea level. Within the agricultural subdivisions, however, the variability of the geophysical attributes is not large.

Table 1. Locations used for determining agroclimatlc characters of pigeonpea areas in India.

Agricultural subdivision	Location	Latitude N °	'	Longitude E °	'	Elevation m
I	Agra	27	10	78	02	169
	Bareilly	28	22	79	24	173
	Delhi	28	35	77	12	216
	Gorakhpur	26	45	83	22	77
	Lucknow	26	45	80	53	128
	Varanasi	25	27	82	52	87
II	Dohad	22	50	74	16	333
	Hoshangabad	22	46	77	46	302
	Indore	22	43	75	48	567
	Jabalpur	23	10	79	57	393
	Kota	25	11	75	51	257
IIIa	Ahmednagar	19	05	74	55	657
	Bijapur	16	49	75	43	594
	Chitradurga	14	14	76	26	733
	Sholapur	17	40	73	54	479
IIIb	Akola	20	42	77	02	282
	Hyderabad	17	27	78	28	545
	Nizamabad	18	40	78	06	381

Table 2. Temperature variation in the major plgeonpea-growlng regions of India during rainy (July—Sept) and poatrainy (Nov—Jan) seasons.

Agricultural subdivision	Rainy season			Postrainy season		
	Tmax	Tmin	Tave	Tmax	Tmin	Tave
	C					
I	33.3	25.9	29.6	25.2	10.1	17.6
II	30.4	23.5	27.0	27.7	11.9	19.8
III	30.1	22.0	26.1	29.5	15.1	22.3
IIIa	29.9	21.2	25.6	29.5	15.7	22.6
IIIb	30.4	22.8	26.6	29.4	14.5	22.0

Tmax = Average daily maximum temperature
Tmin = Average daily minimum temperature
Tave = Average temperature ((Tmax + Tmin)/2j

Meteorological Characteristics

Temperature

Temperature regimes based on 30-year normals (IMD 1967) for the three agricultural subdivisions of India are shown in Table 2 for the rainy and postrainy crop seasons. The average temperature during the rainy crop season is slightly higher in agricultural subdivision I than in subdivisions II and III. The diurnal variation is about 8° C. During the postrainy season agricultural subdivisions I and II have a much lower averageminimumtemperature(about 10°C). In subdivision I, though it is not shown in the average temperature figures, there are nights

Table 3. Variation in snahine hours and global solar radiation[a] in the three major pigeonpea-growlng regions during rainy and postrainy seasons.

Agricultural subdivision	Sunshine (hr/day)		Radiation (cal/cm^2/day)	
	Rainy	Postrainy	Rainy	Postrainy
I	6.5	8.4	420	380
II	4.6	9.2	400	430
III	4.3	9.5	430	410
IIIa	4.0	9.6	440	420
IIIb	4.6	9.3	420	410

a. Calculated as per Reddy (1971) procedure.

when the temperatures drop to around 0° C, and frosts occur, primarily from late December to early February. The incidence of frost is much lower in agricultural subdivision II and no frosts occur in subdivision III. Thetemperature regime during the postrainy season has an important influence on the selection of genotypes of different maturity classes for different agricultural subdivisions.

Global Solar Radiation and Hours of Sunshine

It has been demonstrated in several crop-modeling studies that the amount of dry matter produced by plants depends to a large measure upon the incidence of solar radiation and its extinction in the crop canopy, apart from other plant and environmental factors (Sivakumar and Virmani 1980). The data (Table 3) show that the amount of solar radiation received is about 5 to 10% less in subdivision II than in subdivisions I and III during the rainy crop season. The data are reported on a daily basis, thus over the crop season these will make a substantial difference. A comparison of global solar radiation received in the postrainy season shows that agricultural subdivision I gets the least amount of radiation, followed by subdivision III; subdivision II gets the highest amount of global solar radiation. These differences are due to variations in the cloud cover and geocoordinates of the region under study.

Rainfall

Pigeonpea is primarily grown as a dryland crop; therefore a study of the rainfall characteristics of the pigeonpea-growing areas is important in defining the moisture environment for plant growth.

Pigeonpea-growing areas are located between 600 to 1400 mm mean annual rainfall (Table 4). The mean annual rainfall of agricultural subdivision IIIa is 662 mm, while for the other subdivisions it is 900 mm or more. The number of rainy days varies widely at different locations. Generally, locations with high rainfall have more than 50 rainy days, while the others have around 40 rainy days. In all the agricultural subdivisions, the bulk of the total annual rainfall (80-90%) is received during the rainy season, from June to October. The coefficient of variation of the annual rainfall is quite large — about 30% in subdivision I and III and about 20 to 35% in subdivision II. This means that the amount of annual rainfall and number of rainy days in different agricultural subdivisions vary widely from year to year.

A measure of the dependability of the annual rainfall in meeting crop water needs could be given by comparing the potential evapotranspiration (PE) with the dependable rainfall (DP). DP is defined as the amount of rainfall expected at 75% probability. Results on the amount of DP, PE, and MAI (DP/PE) for selected locations are shown in Table 4. These clearly demonstrate that in agricultural subdivision IIIa, the adequacy of rainfall in relation to potential evapotranspiration demand is quite unfavorable compared with the other regions. Agricultural subdivision II generally receives much higher amounts of rainfall compared with potential evapotranspiration needs.

Table 4. Mean and dependable rainfall and rainy days at selected locatiens in three major plgeonpea-growing regions of India.

Agricultural subdivision	Location	Seasonal rainfall Annual	Rainy (mm)	postrainy	Rainy days	Annual dependable rainfall* (mm)	PE[b] (mm)	MAI[c]
I	Agra	660	625	22	39	508	723	.70
	Barielly	1015	814	33	48	806	675	1.20
	Delhi	637	534	31	37	466	811	.57
	Gorakhpur	1213	900	28	57	1039	663	1.57
	Lucknow	979	783	31	48	768	663	1.16
	Varanasi	1035	874	38	53	871	668	1.30
II	Hoshangabad	1265	1127	37	62	1047	829	1.26
	Indore	896	803	33	50	710	1000	.71
	Jabalpur	1379	1118	48	69	1177	809	1.45
	Kota	758	709	18	40	549	921	.60
IIIa	Ahmednagar	625	375	45	38	458	938	.49
	Chitradgrga	615	266	66	47	493	957	.51
	Sholapur	667	451	38	47	531	1066	.50
IIIb	Akola	771	609	43	48	617	1011	.61
	Hyderabad	746	475	32	52	607	1028	.59
	Nizamabad	976	780	21	62	833	940	.89

a. Based on 1901 to 1950 data (monthly and annual rainfall and number of rainy days, period 1901-1950; India Meteorological Dept 1971).
b. PE = Potential evapotranspiration for the crop season.
c. MAI = Moisture availability index, which is equal to DP/PE, where DP is dependable precipitation and PE is potential evapotranspiration.

Length of the Growing Season

Figure 4 shows the average length of the growing season in different agricultural subdivisions in India. The estimates are based on the comparison of the mean monthly rainfall and PE and the classification does not consider any constraint of temperature. The map has been prepared by the Agroecological Zones Project of the FAO (Frere 1980, personal communication). A study of the core pigeonpea-growing districts in Uttar Pradesh, Bihar, Madhya Pradesh, and eastern Maharashtra shows that these are located between growing-season isohyets of 120 and 180 days. Most of the satellite pigeonpea-growing areas in the states of Karnataka, Andhra Pradesh, and Maharashtra have 90 to 120-day growing seasons. Only one district (Chitradurga) in Karnataka State is classed as a "core" pigeonpea-growing district although the length of the growing season is only 90 to 120 days.

Variability of the Growing Season

The length of the growing season is determined not only by the amount and distribution of the rainfall but also by the water-holding and release characteristics of the soil. Table 5 shows the results of a simulated water balance (Reddy 1979) for seven selected locations representing the three agricultural subdivisions of the pigeonpea-growing areas. Except in subdivision Ilia, the average growing season in these subdivisions is more than 150 days. At 70% probability, the threshold values are in excess of 110 to 120 days in most cases. Agricultural subdivision Illa presents a different situation. Chitradurga, which falls primarily in the north-east seasonal rainfall zone, has an average growing season of only 80 days. At 70% probability the growing season may be as short as 42 days. In the Sholapur area, although the average length of the growing season is 126 days, the stability of the rainfall at the time of sowing

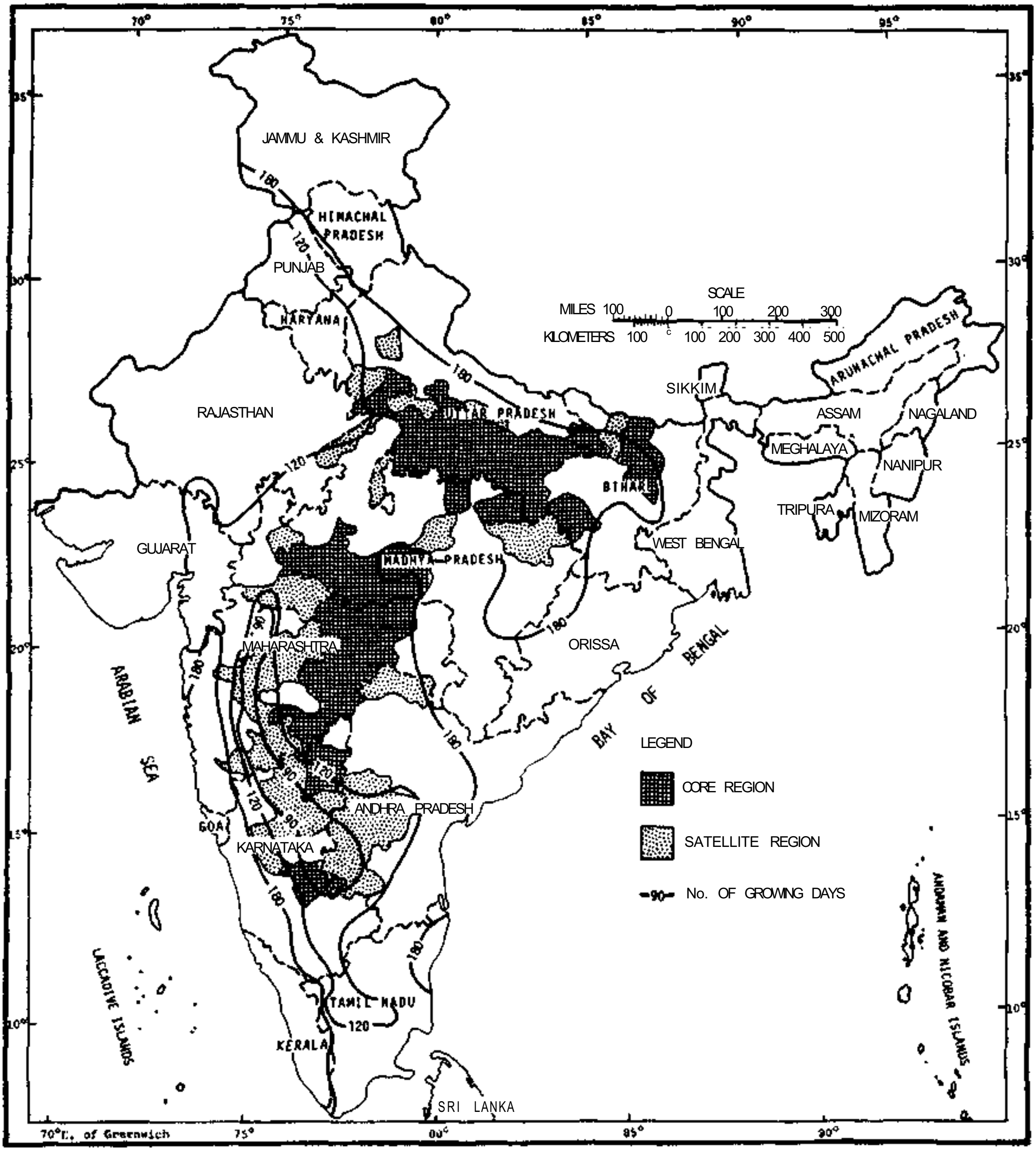

Figure 4. Length of the growing season in pigeonpea regions of India.

of the rainy season crops is quite low. Binswanger et al. (1980) have shown that the probability of adequate moisture for the seedling survival of the crop is around 50%.

Probabilities of Waterlogging

Hargreaves (1974) stated that during the rainy months when MAI (dependable precipitation/potential evapotranspiration) exceeded 1.34 in the semi-arid northeast Brazilian region, the moisture in the root zone was excessive and likely to hamper plant growth. The soils in this region are shallow, stony, and have a low organic matter and clay content.

The pigeonpea-growing areas of India are

Table 5. **Length of the growing season et three probability levels and soil moisture in the root zone at the end of the rainy season at selected locations in the pigeonpea-growing regions of India.**

Agricultural subdivision	Location	Probability level	Length of growing season	Days
I	Agra	Average	2 July-23Dec	168
		70	9 July-9 Dec	154
		30	2 July-4 Feb	217
	Varanasi	Average	25 June-16 Dec	168
		70	2 July-9 Dec	161
		30	25 July-4 Feb	224
II	Indore	Average	10 June-18 Nov	154
		70	2 July-21 Oct	112
		30	11 June-25 Nov	169
IIIa	Sholapur	Average	16 July-18 Nov	126
		70	23July-11 Nov	112
		30	4 June-2 Dec	182
	Chitradurga	Average	17 Sept-2 Dec	77
		70	1 Oct-11 Nov	42
		30	25 June-23 Dec	182
IIIb	Akola	Average	18 June-2 Dec	168
		70	2 July-4 Nov	126
		30	18 June-16 Dec	182
	Hyderabad	Average	18 June-18 Nov	154
		70	9 July-4 Nov	118
		30	18 June-25 Nov	161

primarily located on soils with a much higher water-holding capacity: Vertisols and Indo-Gangetic alluvium. It has been observed at the ICRISAT location that in the deep Vertisols, short-term waterlogging is quite common in the months of July, August, and September. Significant detrimental effect of excessive water in the root zone is observed in September, when the soil profile is almost filled to capacity by July and August rainfall. We feel that locations with 2 successive months of MAI of 0.66 or more pose a waterlogging hazard. The data on monthly MAI for selected locations (Table 6) show that, except for the locations in agricultural subdivision Ilia, all locations receive excessive amounts of rainfall for varying durations. For example, Agra has MAI values of 0.75 and 0.96 forthe months of July and August, showing that drainage requirements are likely to be high in the month of August in most years (at least 3 of 4 years). At Hyderabad, the waterlogging hazard will extend from August to September. In agricultural subdivision II, the problem of waterlogging is quite acute and is likely to extend from July through September.

Isoclimes of Pigeonpea-growing Areas in West Africa

The Inter-African Center for Hydraulic Studies (CIEH 1979) has defined three major bioclimatic zones in the West African regions:

- the southern Sahel region, with 75 to 90 days' growing season,
- the Sudan region with 90 to 165 days' growing season, and
- the northern Guinea region, with 165to210 days' growing season.

Based on a study of monthly MAI for the rainy

Table 6. Moisture availability indax (MAI) for rainy months at selected locations in three major pigeonpea growing regions.

Agricultural subdivision	Location	MAI*				
		June	July	Aug	Sept	Oct
1	Agra	.08	75	.96	.30	.01
	Bareilly	.16	1.42	1.49	.59	.02
	Delhi	.06	.56	.45	.20	.02
	Gorakhpur	.43	1.87	2.04	1.05	.07
	Lucknow	.18	1.51	1.53	.68	.03
	Varanasi	.17	1.47	1.92	1.06	.04
II	Hoshangabad	.40	2.89	2.44	.93	.03
	Indore	.25	1.44	1.13	.67	.03
	Jabalpur	.49	3.11	2.85	1.00	.04
	Kota	.11	1.05	1.16	.32	.01
IIIa	Ahmednagar	.40	.34	.23	.67	.13
	Chitradurga	.24	.37	.34	.47	.40
	Sholapur	.38	.41	.41	.72	.13
IIIb	Akola	.38	1.10	.60	.60	.03
	Hyderabad	.31	.76	.66	.80	.15
	Nizamabad	.40	1.39	1.39	1.15	.08

a. MAI = DP/PE, where DP is the dependable precipitation and PE is the potential evapotranspiration.

Table 7. Moisture availability indax (MAI) for rainy months at selected locations in West Africa.

Location	Country	Latitude		Longitude		MAI[a]				
						June	July	Aug	Sept	Oct
Bignona	Senegal	12	40	16	16	.46	1.82	2.55	1.75	.49
Tambacounda	Senegal	13	46	13	41	.53	1.34	1.95	1.46	.24
Boulel	Senegal	14	17	15	32	.19	.58	1.20	.82	.14
Kalana	Mali	10	47	08	12	.72	1.23	2.27	1.85	.42
Galougo	Mali	13	50	11	04	.66	1.20	1.95	1.16	.14
Diema	Mali	14	33	09	11	.22	.83	1.51	.70	.09
Bamako	Mali	12	38	08	02	.70	1.56	2.27	1.32	.20
Niangoloko	Upper Volta	10	16	04	55	1.03	1.31	2.41	1.76	.29
Ouagadougou	Upper Volta	12	22	01	32	.50	1.03	1.72	.79	.06
Bam (Tourcoing)	Upper Volta	13	20	01	30	.37	.76	1.43	.61	.03
Gaya	Niger	11	59	03	30	.44	.88	1.69	.91	.03
Maradi	Niger	13	28	07	25	.18	.88	1.58	.46	.00
Moundou	Chad	08	34	16	05	1.13	1.77	2.57	1.75	.34
Mongo	Chad	12	11	18	41	.40	1.22	2.37	.82	.10
Am Dam	Chad	12	46	20	40	.24	.87	1.83	.53	.03

a. MAI = DP/PE, where DP is dependable precipitation at 75% probability level and PE is potential evapotranspiration.

crop season of 15 locations (Virmani et al. 1980) representing five West African countries (Table 7), we feel that the southern part of the Sudan bioclimatic region, with a 120-day growing season, and the northern Guinea region, with about a 180-day growing season, are likely to provide a suitable growing environment for pigeonpea (Fig. 5). The crop is likely to do well on deep, heavy-textured soils.

Conclusions

The majority of the core pigeonpea-growing area lies in dependable and high rainfall areas of India. The length of the growing season extends from 120 to 180 days. In northern and northeastern India, although the soil moisture is adequate to sustain the crop in most years, the onset of the cold weather in late November or December limits the growing season.

In the zone of low and erratic rainfall in Maharashtra and Karnataka states, the lack of adequate water on a continuous basis is a serious obstacle to stable pigeonpea yields.

The amount of solar radiation in the rainy season in the central Indian pigeonpea-growing areas is somewhat lower than in the others. Studies need to be initiated to find out threshold values *of* radiation saturation for photosynthesis. If the radiation is inadequate, breeding and selection of cultivars suited to lower light-saturation levels should be initiated.

A major constraint to stabilized and increased production of pigeonpea is likely to be the exposure of the crop to short-term waterlogging. Efforts should be made to introduce land- and water-management techniques that will

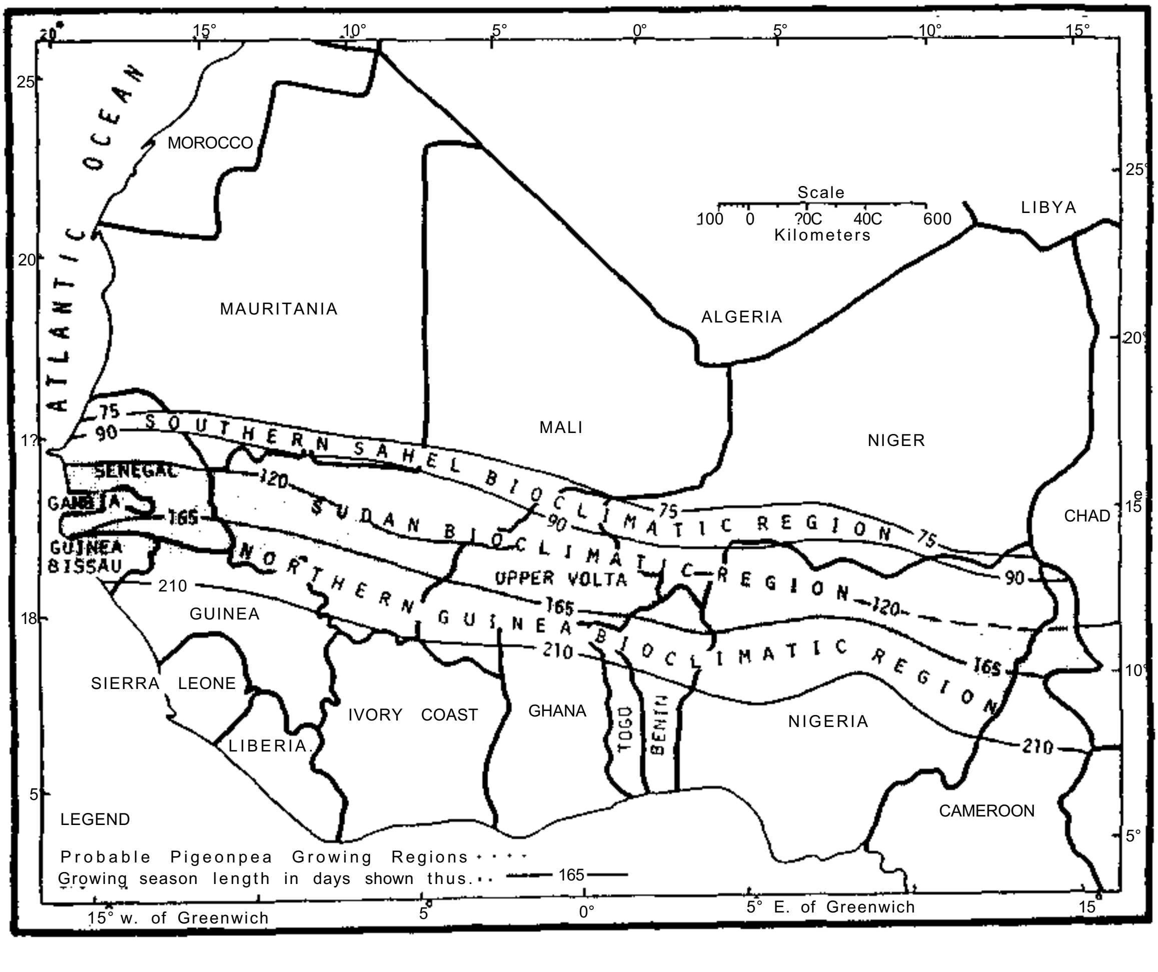

Figure 5. Bioclimatic zones of West Africa.

help drain off excess water from the crop.

Agroclimatic analysis shows that for the states of Uttar Pradesh and Bihar (Agricultural subdivision I) it would be advisable to adopt determinate 120-day pigeonpea types. For the central and southern Indian regions (Agricultural subdivisions II and III), medium to long-duration inderterminate types are likely to be more suitable.

A broad comparison of the climatic attributes of the pigeonpea-growing areas of India with the agroclimatic characteristics of the West African region showed that the area with a 120- to 180-day growing season is likely to suit pigeonpea cultivation. This area comprises parts of the Sudan and northern Guinea bioclimatic zones.

Since the growth habit of the pigeonpea crop is such that it develops ground cover slowly, intercropping it with cereals would be most advantageous from the viewpoint of resource use. Studies on the light- and water-use patterns of different genotypes in diverse environments should be conducted under intercropping pressure to evaluate the efficiency of use of climatic resources.

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References

BINSWANGER, H. P., VIRMANI, S. M., and KAMPEN, J. 1980. Farming systems components for selected areas in India: evidence from ICRISAT. ICRISAT Research Bulletin 2, Patancheru, A.P., India.

CIEH (Centre Inter-Africain etudes Hydrauliques). 1979. Savanna regional water resources and land use. Inter African Committee for Hydraulic Studies 2: 2-20, CIEH-USAID, Ouagadougou, Upper Volta.

EASTER, K. W., and ABEL, M. E. 1973. Cropping regions in India. Economic Development Center Bulletin No. 1, Department of Economics, University of Minnesota, Minneapolis, Minnesota, USA.

HARGREAVES, G. H. 1974. Precipitation dependability and potential for agricultural production in northeast Brazil. EMBRAPA and Utah State University Publication 74-D155, Logan, Utah, USA. 123 pp.

IMD (India Meteorological Department). 1967. Climatological tables of observatories in India (1931-1960). Pune, India: India Meteorological Department.

MURTHY, R. S., and PANDEY, S. 1978. Delineation of agro-ecological regions of India. Commission V, 11th Congress of the International Society of Soil Science. 19-22 June 1978, Edmonton, Canada.

REDDY, S. J. 1971. An empirical method for the estimation of total solar radiation. Solar Energy 13: 289-290.

REDDY, S. J. 1979. A simple method of estimating soil water balance. Agricultural Meteorology. (In press.)

SIVAKUMAR, M. V. K., and VIRMANI, S. M. 1980. Growth and resource use of maize, pigeonpea, and maize/pigeonpea intercrop in an operational research watershed. Experimental Agriculture 17. (In press.)

VIRMANI, S. M., REDDY, S. J., and BOSE, M. N. S. 1980. A handbook on the rainfall climatology of West Africa. Data for selected locations. ICRISAT Information Bulletin 7, Patancheru, A.P., India.

Water Use by a Maize/Pigeonpea Intercrop on a Deep Vertisol

Sardar Singh and M. B. Russell*

Abstract

Field studies were conducted on maize/pigeonpea intercrop for 2 years on a deep Vertisol at the ICRISAT Center. After the harvest of the maize crop the pigeonpea transpired almost as much as its potential rate. The transpiration declined as the season progressed because of the progressive depletion of the available profile water supply. From late vegetative growth (84 days after sowing) through harvest (200 days after sowing) the transpiration was 200 mm of water. During that 116-day period the evapotranspiration was about half the open-pan evaporation;

Though the roots of the pigeonpea were effective in removing water from the entire 187-cm profile, about half of its water was obtained from the upper 52-cm layer. Rates of water extraction by roots ranged from 0.003 to 0.055 mm/cm/day and varied with time, depth in the profile, and available water content.

Pigeonpea has such plasticity that even in drought years, when other crops fail, it is capable of producing someyield (Pathak 1970). It is recognized that because of this plasticity pigeonpea can fit into intercropping systems with a large number of crops such as maize, sorghum, or millet (Saxena and Yadav 1975). Hence pigeonpea is seldom grown in pure stands on a field scale, but is mostly cultivated as an intercrop or as a mixed crop. After the harvest of the cereal, pigeonpea matures on the residual soil moisture. However, the contribution of stored soil water to evapotranspiration, and particularly its time sequence, has not been adequately evaluated.

Each crop has a characteristic water-use pattern throughout the season. This is determined largely by the length of the growth period and by the seasonal atmospheric evaporative demand. The depth and porosity of the soil determine its capacity to store water and to release it to roots.

Several workers have used the water-balance equation as a means of estimating crop water use (Greacen and Hignett 1976; Rosenthal et al. 1977; Piara Singh and Russell 1979; Tanner and Jury 1976).

Pigeonpea is grown exclusively in tropical areas. The moisture stored in the soil profile during the rainy season is used by the crop in the postrainy season. Under such conditions, proper accounting of profile moisture changes is important for predicting plant behavior. Therefore we studied the water balance and profile water-loss pattern of a deep Vertisol cropped to maize/pigeonpea during the 1977 and 1978 rainy seasons, and water-use pattern of pigeonpea in the subsequent postrainy season. Rainfall, open-pan evaporation, runoff, and the time and depth changes in profile water content were measured, and drainage, evaporation, and transpiration losses were computed.

Materials and Methods

The experiments were conducted during both the rainy and postrainy season of 1977 and 1978 at the ICRISAT research center near Hyderabad, India. The soil is a deep Vertisol having a uniform clay content of 50 to 60%, and bulk density of 1.4 g/cc to a depth of 187 cm. It is classified as a deep clayey and montmorillonitic,calcareous memberof the hyperthermic

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family of typic Pellusterts. The volumetric water content at 15 bar and the in-situ field capacity are 0.27 and 0.44cc/cc respectively. Soil is low in organic matter, nitrogen, phosphorus, and often zinc. Potassium level is adequate and the pH is 8.0.

Runoff (R), profile water content to 187 cm (M) and water flux at 187 cm (D) were determined on a 20 x 60 m plot and a nearby 3-ha watershed. Twenty-four neutron probe access tubes in the plot and 30 in the watershed were used to monitor soil moisture at 15-cm intervals from 30 to 180 cm at roughly fortnightly intervals. Runoff was measured by water stage recorders and V-notch weirs on the plots and by a Parshall flume on the watershed. Ten composite gravimetric samples at 0 to 10 and 10 to 20-cm were taken from the plot and the watershed subunit and used with the neutron-probe data to determine the 0 to 187 cm volumetric water content (∂v) as a function of depth and time. Rainfall (P) and class A open-pan evaporation (Eo) were measured daily at the ICRISAT meteorological station adjacent to the experimental area.

The maize/pigeonpea intercrop was sown on 150-cm beds separated by furrows having a 0.6% slope. The details of the other management practices are given in Table 1.

The water balance equation is an expression of the law of conservation of matter, which can be written as: water added (rain P) plus irrigation (I) equals change in profile water content (AM) plus runoff (R) plus drainage (D) plus evaporation (E) plus transpiration (T), i.e., $P + I = \Delta M + R + D + E + T$. The term (I) in the equation is used only when irrigation is applied. In this study, P, A M, and R were measured, D was estimated as a decay function of the daily excess over the profile capacity. Evaporation,E, is estimated as explained below, and T was taken as the residual of the equation. This estimated transpiration based on mass balance is designated T_m and may be compared with estimated transpiration T. based on energy-balance considerations.

Estimation of E and Taare based on open-pan evaporation (Eo), the days after the soil surface is wetted (t), and the fraction of radiant energy reaching the soil surface (ß). The latter is measured directly or inferred from measured values of leaf area index (LAI). In this study the daily evaporation from the uncropped soil surface (E*) was computed as E* = Eo/t and the actual soil evaporation (E) estimated as E = ß E*. Daily transpiration based on energy considerations was computed as $T_a + (1-\beta)$ Eo. This assumes no advective energy and no moisture stress to the plant. The daily values of E and T_a are summed to give the values for the various periods.

Results and Discussion

Profile Moisture Changes

The time and depth patterns of volumetric water content are shown in Figure 1. The volumetric water content as a function of depth and time was so similar for the 2 years during the monsoon season that only the curves for the watershed are shown. They clearly show the seasonal progression of the recharging process downward through the profile and the more rapid recharging and depletion that occurred in the upper part of the profile.

Table 1. Management practices used for a maize/pigeonpea Intercrop, ICRISAT Center.

Season	Plot size (ha)	Crop	Cultivar	Fertilizer	Planting date	Harvest date
1977-78		Maize/	Vittal	100-15-0	15 June	10 Oct
BW1	2.00	Pigeonpea	ICP-1		15 June	20 Dec
BW3	0.12	Maize/	Vittal	100-15-0	15 June	21 Sept
		Pigeonpea	ICP-1		15 June	19 Jan
1978-79		Maize/	Composite ASI-54	100-15-0	11 June	26 Oct
BW1	2.0	Pigeonpea	ICP-1		16 June	13 Jan
BW3	0.12	Maize/	Composite ASI-54	100-15-0	12 June	20 Oct
		Pigeonpea	ICP-1		12 June	3 Jan

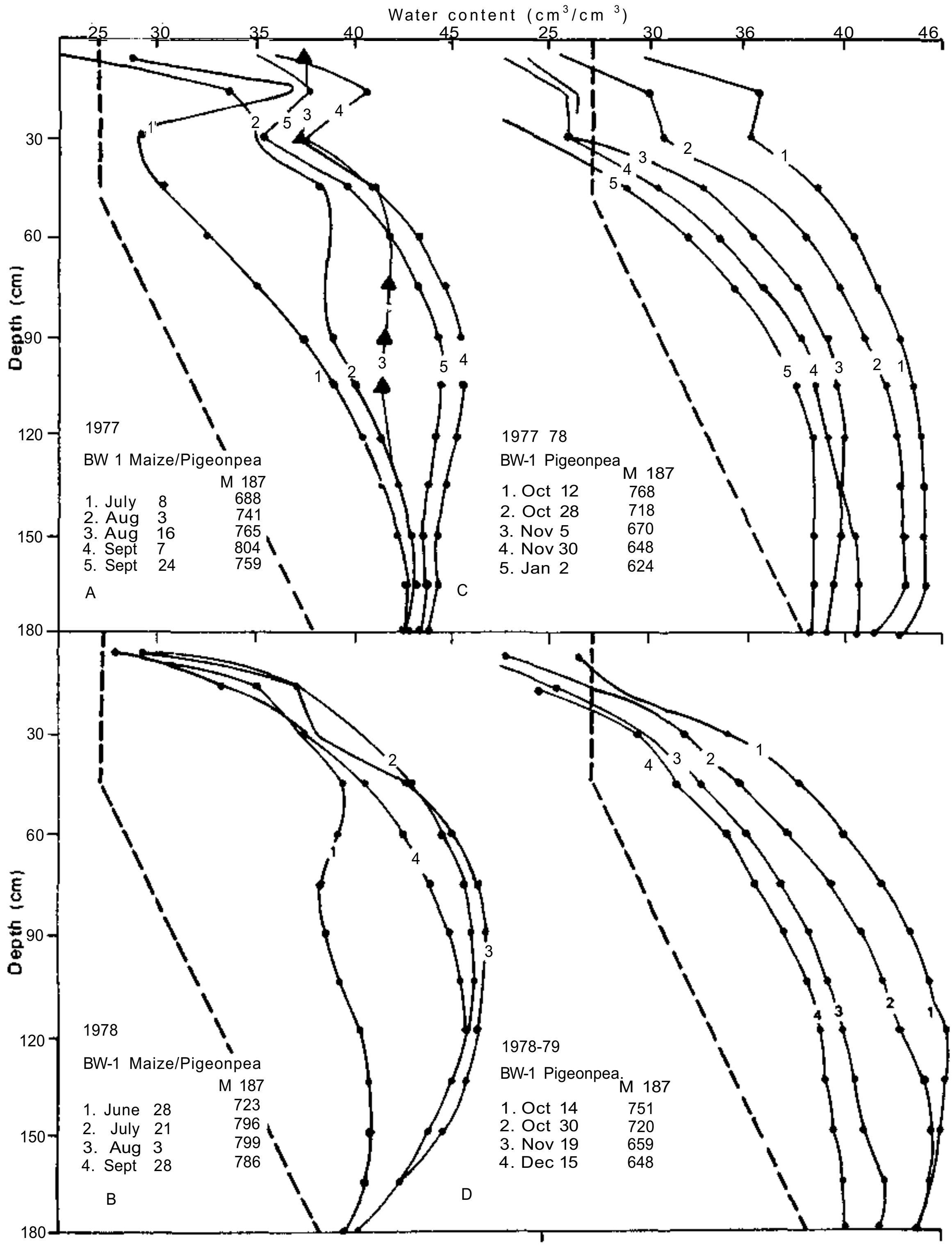

Figure 1. Time and depth patterns of profile water content during the rainy (A-B) and postrainy season (C-D).

At the beginning of the monsoon season — curves not shown in Figure 1 — the profile was depleted below the 15-bar value to a depth of 30 to 45 cm. From that depth to 187 cm there were about 75 mm and 80 mm of water available during the 1977 and 1978 monsoon season, respectively.

The progressive depletion of the profile by the pigeonpea during the postrainy season is clearly shown by the curves CD in Figure 1. Differences in the time course of depletion at various depths by pigeonpea are apparent from the curves.

Water Balance

The several components of the water-balance equation during different periods of 1977-78 and 1978-79 for both monsoon and postmonsoon seasons for maize with a pigeonpea intercrop are presented in Tables 2 and 3.

Table 2. Water-balance components for maize/pigeonpea intercrop for 10 periods during the rainy and postrainy seasons in a deep Vertisol.

Calendar period	Days	P	Eo	E*	ΔM	E	R	D	Tm	Te
		(mm)								
BW1 1977-78										
13 June-8 July	25	120	187	86	11	84			25	4
8 July-3 Aug	26	130	144	91	53	64			13	43
3 Aug-16 Aug	13	92	60	27	24	9			59	39
16 Aug - 7 Sept	22	123	33	39	39	10			74	62
7 Sept - 24 Sept	17	1	99	15	-45	5			41	50
24 Sept- 12 Oct	18	62	82	43	1	22			39	41
12 Oct-28 Oct	16	12	81	28	-42	11			43	47
28 Oct-15 Nov	18	22	98	24	-48	6			64	74
15 Nov-30 Nov	15	16	61	8	-22	2			26	46
30 Nov-2 Jan	33	2	149	5	-24	2			24	90
Total	203	580	994	366	-53	215			408	496
Fraction of rainfall				0.63		0.37			0.70	
BW3 1977-78										
22 June- 14 July	22	61	164	59	- 9	44	2		24	41
14 July- 1 Aug	18	129	89	62	68	19			42	61
1 Aug- 18 Aug	17	94	85	30	12	3	2	14	77	76
18 Aug - 8 Sept	21	124	76	55	40	14			56	57
8 Sept - 22 Sept	14	-	82	11	-25	4			21	52
22 Sept-24 Oct	32	75	159	56	-37	11			101	127
24 Oct - 9 Nov	16	17	88	17	-32	2			47	78
9 Nov - 23 Nov	14	5	67	9	-35	2			38	54
23 Nov - 7 Dec	14	8	57	4	-15	1			22	41
7 Dec-21 Jan	45	17	199	22	- 7	12			12	91
Total	213	530	1066	325	-40	112	4	14	440	678
Fraction of rainfall				0.61		0.21		0.03	0.83	

P = rainfall
ED = open pan evaporation
E* = potential soil evaporation
ΔM = change in profile moisture to 187 cm
E = soil evaporation
R = runoff
D = drainage beyond 187 cm calculated from water balance using open pan as ET
Tm = mass balance transpiration
Te = energy balance transpiration

Table 3. Water-balance components for maize/pigeonpea intercrop for 11 periods during the rainy and postrainy seasons in a deep Vertisol.

Calendar period	Days	P	Eo	ΔM	E	Tm	R	D
		(mm)						
BW1 1978-79								
1 June-28 June	27	181	220	+81	90	0	10	
28 June-21 July	23	180	126	+ 74	60	23	12	
21 July-9 Aug	19	118	92	+ 2	20	72	0	24
9 Aug - 8 Sept	30	452	114	+ 21	25	90	250	65
8 Sept - 28 Sept	20	75	75	-36	15	61	0	35
28 Sept- 14 Oct	16	50	81	-33	20	30	0	30
14 Oct -30 Oct	16	8	81	-31	10	30	0	0
30 Oct- 14 Nov	15	22	56	-18	10	30	0	0
14 Nov-29 Nov	15	0	72	-34	4	30	0	0
29 Nov-15 Dec	16	0	77	-21	0	21	0	0
15 Dec-2 Jan	18	0	83	+ 1	0	0	0	0
Total	215	1086	1077	+ 6	254	387	272	154
Fraction of rainfall					0.23	0.36	0.24	0.14
BW3 1978-79								
13 June-24 June	11	159	53	+ 107	42	3	7	-
24 June- 10 July	16	75	110	+ 57	40	-22	-	-
10 July-24 July	14	124	61	- 1	20	33	2	70
24 July - 4 Sept	42	574	167	+ 34	33	134	226	147
4 Sept- 18 Sept	14	43	68	- 1	14	24	-	6
18 Sept - 10 Oct	22	76	90	+ 7	40	29	-	-
10 Oct-23 Oct	13	26	69	-63	30	59	-	-
23 Oct - 10 Nov	18	17	80	-46	21	42	-	-
10 Nov-28 Nov	19	1	83	-41	6	36	-	-
28 Nov-22 Dec	24	-	103	-32	2	30	-	-
22 Dec-3 Jan	12	-	54	- 9	2	7	-	-
Total	205	1095	938	+ 12	250	375	235	223
Fraction of rainfall					0.23	0.34	0.21	0.20

P = rainfall
Eo = open pan evaporation
E* = potential soil evaporation
ΔM = change in profile moisture to 187 cm
E = soil evaporation
R = runoff
D = drainage beyond 187 cm calculated from water balance using open pan as ET
Tm = mass balance transpiration
Ta = energy balance transpiration

The amount of rain in 1977 was only about half that of the 1978 monsoon but was well distributed throughoutthe season. Evaporation constituted a significant part of the seasonal water loss, being about one-fifth of the rainfall and Eo and about one-half of transpiration. At the beginning of the season when plants were small and the ß values were large, the soil was repeatedly wetted by rains; consequently the daily potential evaporation E* values were also high. The product of the two gave large soil evaporation values and, as a consequence, nearly half of the seasonal evaporation occurred in the first 30 days after planting. Evaporation also increased significantly when the maize crop was harvested and the pigeonpea had still not produced reasonable ground cover.

Very little runoff and drainage occurred in 1977, but during the monsoon season of 1978, runoff and drainage was equivalent to one-fifth of the total annual rainfall.

In the latter part of the growing season, transpiration was a major portion of the total loss of water. Good agreement between Tm and Te was observed from mid-July to mid-September, which supported the view that the crops did not experience moisture stress. Although some stress may have developed at shallow depths during the latter part of the period, maturation of maize was the major factor responsible for the decline in transpiration (Tm) below its energy-dependent potential value (Te) in the later part of the monsoon season. In 1978-79 in the BW3 plot, the negative Tm values early in the season are attributed to the overestimation of evaporation E, which may have been caused by an overestimate of potential evaporation or *ß,* or both. During periods of high rainfall, Tm was consistently greater than Te, probably because of the underestimation of drainage, which may indicate that the assumed profile capacity of 815 mm was too high.

For the pigeonpea after the harvest of the maize crop, the differences between Tm and T_e tended to increase as the season progressed. The crop was well established at the beginning of the season, and since the profile was well recharged at that time, the pigeonpea transpired close to its potential rate and Tm $\cong$ Te. In subsequent periods, Tm was smaller than Te because of the progressive depletion of the available profile water supply and the resultant moisture stress in the crop. In BW3 at the end of the rainy season in 1978-79, Tmcontinued to be larger than Te. The ß values were unrealistically large (0.85), probably due to mature maize left in the field. This large value of ß in this period led to the overestimation of Tm and underestimation of Te.

The early October moisture profile data showed that the 187-cm profile contained about 200 mm and 225 mm of available water in 1977 and 1978, respectively. By the end of the season, these dropped to 75 mm in 1977 and to 84 mm in 1978; these represented 33 and 36% of available water, respectively. At the end of the season, the 187-cm profile still contained 650 mm of water. This was virtually the same amount as it contained in the preceding June.

In 1977 and 1978, in BWI, pigeonpea transpired 240 mm and 200 mm in the 116 days beginning on 8 September. The higher value of transpiration in 1977 may be due to underestimation of drainage, or evaporation, or both, during the postrainy season. During this period, 50 mm and 60 mm of evaporation occurred in 1977 and 1978 respectively. Thus the evapotranspiration during the 116 days beginning 8 September was about half the open-pan evaporation (Tables 4 and 5).

Root Extraction Rates

The amount of water extracted by roots of pigeonpea from the deep Vertisol during five periods of the postrainy season are summarized in Table 6. The rains during the 1977 season only partially recharged the upper two profile layers, but in 1978 the entire profile was recharged and 30 mm drainage was computed during the 28 Sept to 30 Oct period. The data in the table were calculated from the profile depletion curves and from daily water balances for the periods following rains. For the season the crop obtained 50 and 40% of its water from the upper 52 cm of the profile in 1977 and 1978 respectively.

As a result of cyclical refillings and depletions, the total water extracted during the season from the 0 to 22-cm layer exceeded the capacity of this layer. The capacity use factors (CUF), i.e., the seasonal withdrawal divided by the layer capacity for each of the six layers for pigeonpea were 2.2, 0.7, 0.6, 0.6, 0.6, and 0.7 in 1977, and 1.0, 0.5, 0.6, 0.6, 0.6, and 0.6 in 1978. These indicate that pigeonpea roots were effective in removing water through the entire 187-cm Vertisol profile.

The time and depth curves of profile water depletion were used to compute the rates of water extraction by roots. During periods of monotonic profile depletion, such extraction rates are interpreted as the de facto root distribution of the crop. Seasonal changes in root extraction rates of pigeonpea from the deep Vertisol for 1977-78 are shown in Figure 2. Also shown are the changes in fractional available water at various depths in the profile.

The seasonal progression in depth and time

Table 4. Postralny-season water balances for plgeonpea on a deep Vartisol.

Period	Rainfall	Open-pan evaporation	Profile water change	Evaporation	Transpiration Tm	T.	Tm/Eo
	(mm)						
BW1 1977							
24 Sept- 12 Oct	62	82	+ 1	22	39	41	0.48
12 Oct-28 Oct	12	81	-42	11	43	47	0.53
28 Oct-15 Nov	22	98	-42	6	64	74	0.65
15 Nov-30 Nov	6	61	-22	2	26	46	0.42
30 Nov-2 Jan	2	149	-24	2	24	90	0.16
Total	104	471	-129	43	196	298	0.42
BW1 1978							
28 Sept- 14 Oct	50	81	-33	20	30		0.37
14 Oct-30 Oct	8	81	-31	10	30		0.37
30 Oct- 14 Nov	22	56	-18	10	30		0.54
14 Nov-29 Nov	0	72	-34	4	30		0.42
29 Nov-15 Dec	0	77	-21	0	21		0.27
15 Dec-2 Jan	0	83	+ 1	0	0		
Total	80	450	-136	44	141		0.31

Table 5. Postrainy-seaaon water balances for plgeonpea on a deep Vertlsol.

Period	Rainfall	Open-pan evaporation	Profile water change	Evaporation	Transpiration T_m	Te	T_m/E_o
	(mm)						
BW3 1977-78							
22 Sept-24 Oct	75	159	-37	11	101	127	0.63
24 Oct-9 Nov	17	88	-32	2	47	78	0.53
9 Nov-23 Nov	5	67	-35	2	38	54	0.25
23 Nov - 7 Oct	8	57	-15	1	22	41	0.39
7 Oct-21 Jan	17	199	- 7	12	12	91	0.06
Total	122	570	-126	28	220	391	0.39
BW3 1978-79							
18 Sept- 10 Oct	76	90	-63	40	29		0.32
10 Oct-23 Oct	26	69	-46	30	59		0.86
23 Oct-10 Nov	17	80	-41	21	42		0.52
10 Nov-28 Nov	1	83	-32	6	36		0.43
28 Nov - 22 Dec	0	103	- 9	2	30		0.29
22 Dec-3 Jan	0	54	+ 12	4	7		0.13
Total	120	479	-179	103	203		0.42

of the root extraction rate of pigeonpeas shows that in the 0 to 22-cm layer the rate of water use remained 0.022 mm/cm/day until the end of November, even though the average fractional available water content was low for each of the five periods. This suggests that the layer was well ramified by roots that were able (1) to exploit quickly and effectively the short-term increases in water in the 0 to 22-cm layer resulting from the small showers during those

Table 6. Profile water use by pigeonpea during postrainy season from a deep Vertlsol.

Period	Days	Water use at depth of (cm) 0-22	22-52	52-82	82-112	112-142	142-187	Total
		(mm)						
BW1 1977-78								
24 Sept- 12 Oct	18	20	5	4	4	2	0	35
12 Oct-28 Oct	16	13	11	7	4	3	4	42
28 Oct-15 Nov	18	23	11	7	7	8	9	65
15 Nov-30 Nov	15	6	3	5	3	3	6	24
30 Nov-2 Jan	33	1	5	5	4	2	4	23
Seasonal total	100	63	35	28	22	18	23	189
Fraction of Total		0.33	0.18	0.15	0.12	0.10	0.12	
BW1 1978-79								
28 Sept- 14 Oct	16	9	10	11	4	1	0	35
14 Oct-30 Oct	16	4	8	4	8	5	0	29
30 Oct- 14 Nov	15	10	2	3	3	5	5	28
14 Nov-29 Nov	15	4	5	4	5	5	6	29
29 Nov - 15 Dec	16	3	1	4	3	4	7	22
Seasonal total	78	30	26	26	23	20	18	143
Fraction of total		0.21	0.18	0.18	0.16	0.14	0.13	

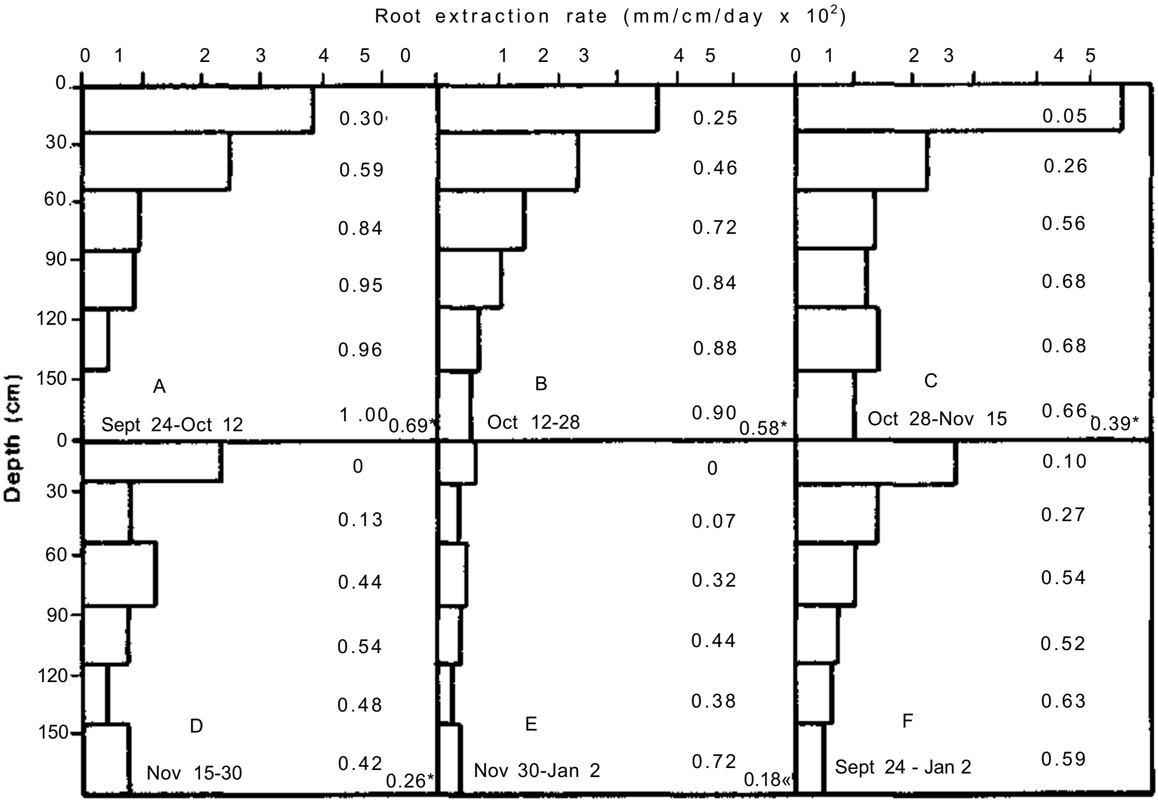

Figure 2. Root extraction rates by pigeonpea and fractional available moisture for six layers of a deep Vertisol.

periods and (2) to effectively extract water down to the 15 bars.

The vertical distribution of extraction rates for the 12 to 28 Oct period (Fig. 2b) is believed to give a realistic picture of the root distribution of the pigeonpea crop; since at that time the profile was well supplied with water at all depths, the extraction rates should have reflected rooting density. At depths from 22 to 112 cm, there was a gradual decline with time in extraction rates corresponding to the decline in fractional available water. The relative importance of extraction at depths below 142 cm increased as the rates in the upper layers declined. Because of the way in which the lower limit of available water for different layers was determined from field measurements, and include the effect of root depth and duration, the low fractional water content in the lower layers does not imply high suction values.

The numbers with an asterisk in Figures 2a to 2e are the weighted profile available water fractions. They were computed by multiplying the fractional available water content of each layer by the estimated relative root concentration in that layer (as inferred from Figure 2b) and summing over the six layers. The resulting values are believed to give a realistic picture of the declining profile water supply to which the crop was exposed during the postrainy season.

When based on the seasonal water extracted, the mean root extraction rates for the layers (Fig. 2f) may also be taken as an integrated picture of pigeonpea root distribution.

During the rainy period in 1978, in BW3 prior to 10 October, water use by pigeonpea was confined to the upper 52 cm of the profile whose available water fraction (AWF) remained above 0.5 (Fig. 3). After that date, profile depletion proceeded downward progressively, and AWF was less than 0.5 continuously from mid-October in the 0 to 22 and 22- to 52-cm layers and from mid-November for the 52- to 97-cm layer. The AWF for the 187-cm profile was 0.30 at harvest on 21 December; however, the AWF of the individual layers was weighted by using the relative extraction rates during the October 10 to 23 period as proxies for relative root density. The residual available water fraction at harvest was only 0.14.

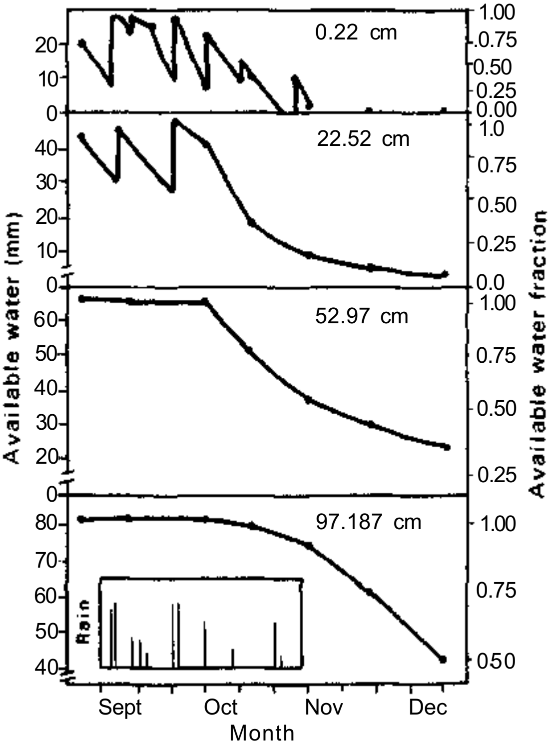

Figure 3. Changes in available water in four layers of a deep Vertisol soil in postrainy season under pigeonpea.

Cumulative Transpiration, Evaporation, and Available Profile Water

Figure 4 shows the way in which the water supply, i.e., rainfall and available profile water, varied during the 215-day period following 1 June in 1978. The amount and seasonal distribution of evaporation and transpiration by monsoon maize/pigeonpea and by pigeonpea in the postmonsoon season also are shown. The available water in the 187-cm profile increased from 80 mm at the beginning of the monsoon to about 200 mm by early July. Dueto frequent rains in August and September the profile remained filled to capacity till the end of September. Theprofile supply declined steadily first by evaporation and, after early October, by transpiration by pigeonpea (Fig. 5). It reached a minimum 80 mm, i.e., 36% of capacity by middle of January. During the 100 day period from 12 October 1977 to 2 January 1978 the average transpiration rate of pigeonpea was half the open pan rate. The corresponding value for 1978-79 was 40% (Fig. 6).

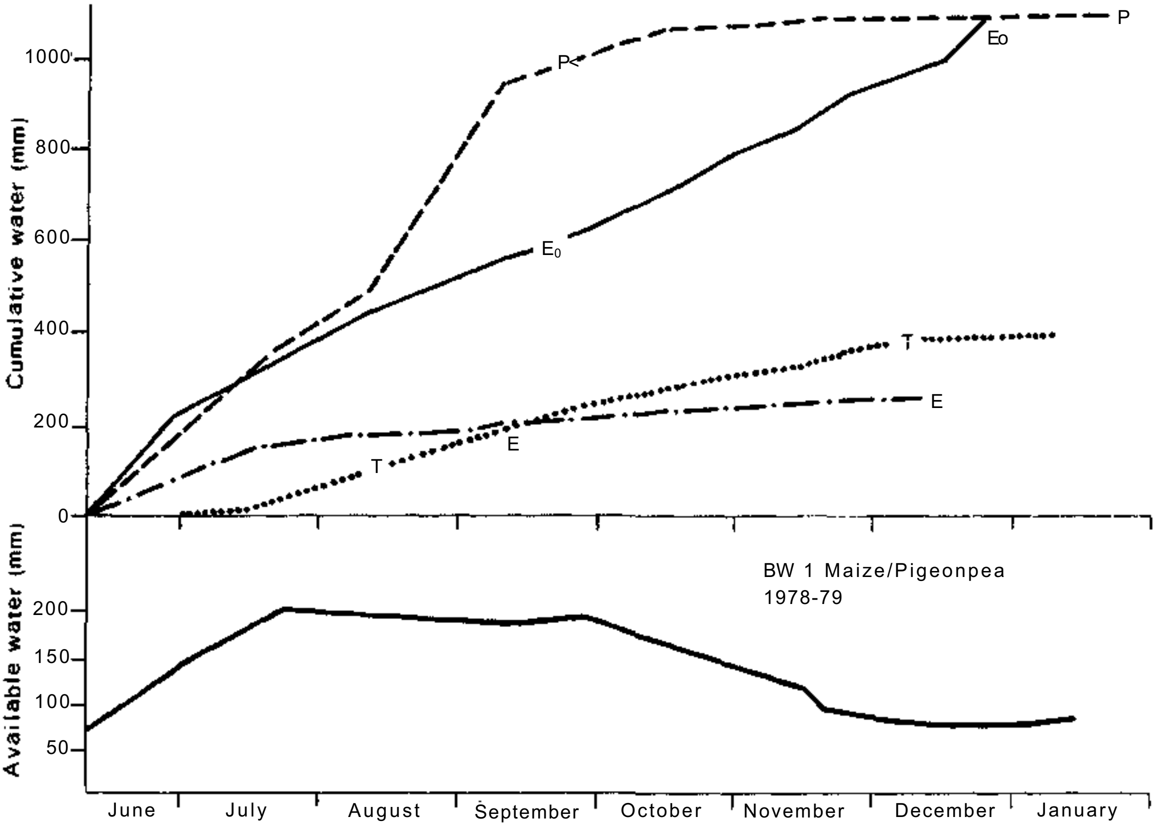

Figure 4. Cumulative rainfall, open-pan evaporation, transpiration, evaporation, and available profile moisture in a deep Vertisol.

In October 1977, 25 mm more rain occured than in 1978, which enabled pigeonpea to transpire at a greater rate and consequently deplete the available water at a much faster rate in 1977-78 than in 1978-79 (Fig. 5).

Yield and Water-Use Efficiencies

The yields and water-use efficiencies (WUE) of maize and pigeonpea crops for BWI are given in Table 7.

Maize yields were very similar in the 2 years and seasonal transpiration was not very different, even though the seasonal available water in 1978 was double that in 1977. Due to insects, pigeonpea yields were significantly less in 1978-79 than in the previous year, though the crop had nearly the same seasonal available water in the profile.

When expressed as weight of grain produced per unit of water transpired (WUE-1), the efficiency of water use was higher for maize than pigeonpea. The water-use efficiency was slightly higher in 1977 than 1978. The water-use efficiency calculated for pigeonpea may be a little overestimated, because it was based on water used after the maize harvest, when the pigeonpea was already established and had used some water in the rainy season. Because the intercrop pigeonpea produced only around 15% of its total dry matter by the time the cereal was harvested (ICRISAT Cropping Systems report 1977-78), if the water used for that growth were taken into account, the water-use efficiency would be still lowerthanthatcalculated above. The decline in WUE-1 1978-79 in the pigeonpea is attributed to the effect of the late season moisture stress that undoubtedly reduced yields. Water-use efficiency was thus reduced, since it is usually directly related to yield.

Water-use efficiency can also be expressed as

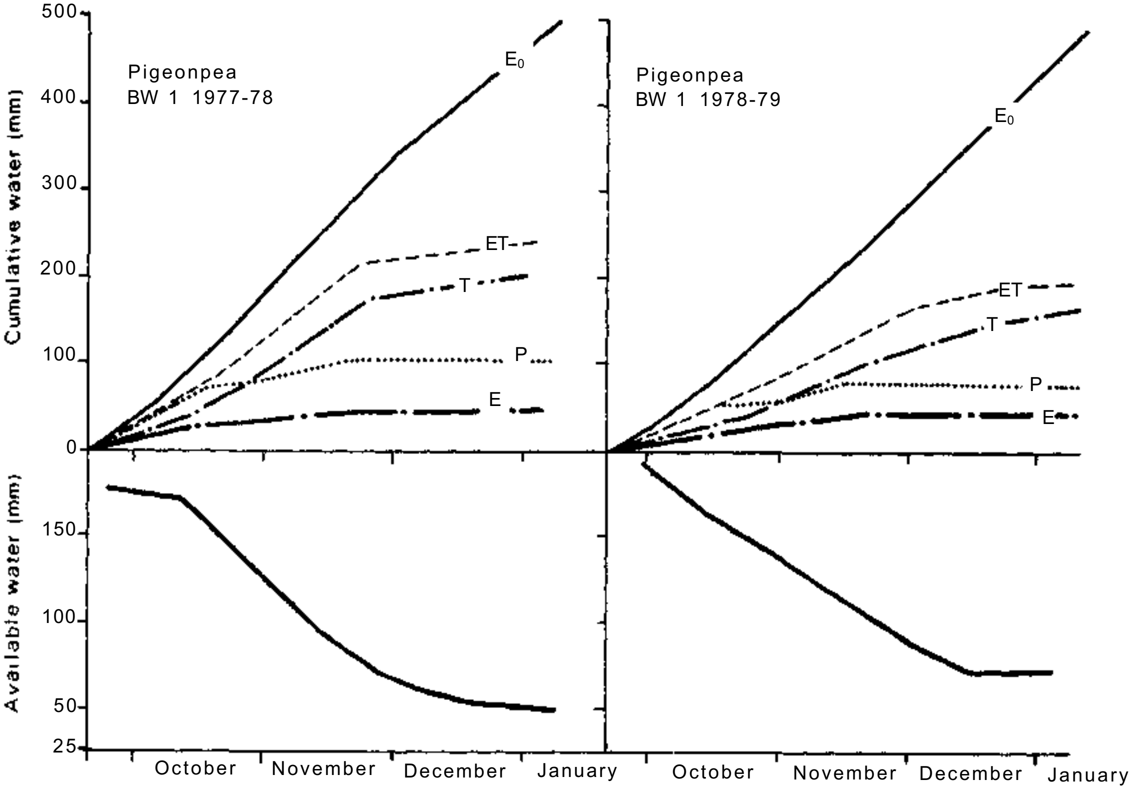

Figure 5. Cumulative rainfall, open-pan evaporation, transpiration, evaporation, evapotranspiration, and available profile moisture in a deep Vertisol.

Table 7. Yields and water-use efficiencies of maize and pigeonpea crops on a deep Vertisol (BW1).

Crop	Yield (kg/ha)	T_m (cm)	AW (cm)	Water-use efficiency (WUE) kg/ha/cm 1	kg/ha/cm 2	cm/cm 3
BW1 1977-78						
Rainy season						
Maize/pigeonpea	2490	21.2	57.3	117.5	43.5	0.37
Postrainy season						
Pigeonpea	1580	19.6	29.3	80.6	53.9	0.67
BW1 1978-79						
Rainy season						
Maize/pigeonpea	2530	24.6	114.0	102.8	22.2	0.22
Postrainy season						
Pigeonpea	1070	14.1	27.1	75.9	39.5	0.52

Tm = Transpiration
WUE-1 = Yield per unit of water transpired
WUE-2 = Yield per unit of water available
WUE-3 = Fraction of seasonal available water transpired
AW = Seasonal available water- M+ P where M = available profile water to 187 cm at planting.

weight of grain produced per unit available water to which the crop had access during the growing *season* (WUE-2). The WUE-2 values were lower than the corresponding WUE-1 values, since the denominator in their ratio includes water lost by evaporation and the residual available water in the root zone at harvest, as well as the quantity transpired.

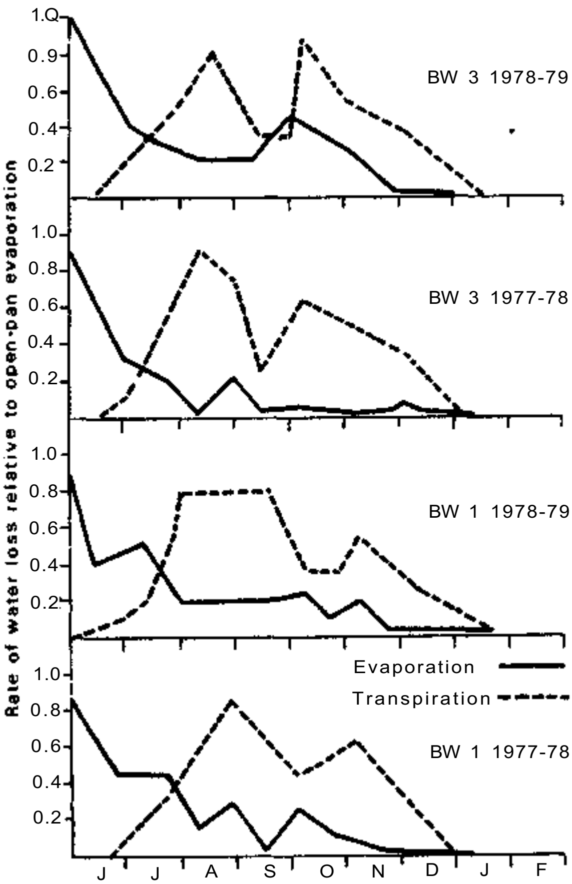

Figure 6. Seasonal trends of evaporation and transpiration for maizelpigeonpea intercrop in a deep Vertisol.

A third method of expressing water-use efficiency is to compute the fraction of seasonally available water that the crop transpires (WUE-3). Using this criterion of efficiency, it is clear that pigeonpea was more efficient in using the available water in the postrainy season than maize was in the monsoon season.

Referencos

GREACEN, E. L., and HIGNETT, C. T. 1976. A water balance model and supply index for wheat in South Australia. CSIRO, Division of Soils Technical paper 27, Canberra, Australia.

ICRISAT, 1978. Annual Report 1977-78. Patancheru, A.P. 502 324, India: ICRISAT.

PATHAK, G. N. 1970. Red gram. Pages 14-53 *in* Pulse crops of India, ed. P. Kachroo, New Delhi, India: Indian Council of Agricultural Research.

PIARA SINGH and RUSSELL, M. B. 1979. Water balance and profile moisture loss patterns of an Alfisol. Agronomy Journal 71: 963-968.

ROSENTHAL, W. D., KANEMASU, E. T., RANEY, R. J., and STONE, L. R. 1977. Evaluation of an evapotranspiration model for corn. Agronomy Journal 69: 461-464.

SAXENA, M. C., and YADAV, D. S. 1975. Some agronomic considerations of pigeonpeas and chickpeas. Pages 31-61 *in* Proceedings, International Workshop on Grain Legumes. ICRISAT, 13-16 Jan 1975, Hyderabad, India.

TANNER, C. B., and JURY, W. A. 1976. Estimating evaporation and transpiration from a row crop during incomplete cover. Agronomy Journal 68: 239-243.

Water Availability and Grain Yield in Pigeonpea

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Abstract

This paper evaluates the experiments conducted on early pigeonpea types at different locations to show that pigeonpea suffers damage both from excess water and from poor availability of water. However, it is difficult to define the adequate requirement in relation to yield. When irrigation was applied after commencement of flowering, there was increase in biomass in short-, medium-, and long-duration varieties. However, the increase in grain yield and biomass did not follow the same pattern. Consequently, higher yield in cv Prabhat was due to an increase in harvest index, whereas in other varieties increase in yield occurred because of increase in biomass. The effect of water application on the postflowering period has also been described, and the compensation capacity of the plant has been highlighted. Control of vegetative growth in relation to water availability has been argued as a selection criterion for improving the yield of this crop in monoculture.

Pigeonpea *(Cajanus cajan)* is grown mostly as a *kharif* (rainy season) crop in India (Rachie and Roberts 1974; Sinha 1977). Traditionally, this crop has been grown as a mixed crop with millets or sorghum. The millet or sorghum is generally harvested earlier, and pigeonpea continues in the field. On dryland this enables utilization of residual moisture or any rain that comes after the harvest of millet or sorghum, which may be why pigeonpea is labeled as a dryland crop. An indeterminate habit is advantageous for such situations; therefore, most of the older varieties were indeterminate, long-duration types. The requirements of intensive agriculture have prompted scientists to evolve short-duration pigeonpeas suitable for monoculture, but even so, pigeonpea is largely treated as a dryland crop. Consequently, very little effort has been made to determine its water requirement.

Yield Variation

Three groups of cultivars, differing essentially in their maturity duration, are recognized: short-duration (120-130 days), medium (150-170 days), and long-duration (above 180 days). In most instances, the yield corresponds to the duration of the maturity. Because the short-duration varieties are important in intensive agriculture, their water requirement is particularly important; this paper is therefore confined mostly to studies on short-duration varieties.

In the All-India Coordinated Project on Improvement of Pulses, short-duration varieties have been tested year after year. Two cultivars — Prabhat and T-21 — were grown at 11 locations in 1975; the results indicated that the yield of Prabhat varied from 833 kg/ha to 1622 kg/ha and that of T-21 from 502 kg/ha to 2323 kg/ha (Table 1). The rainfall during the crop season ranged from 398 mm to 1412 mm at Hissar and Pantnagar respectively. However, the maximum yield of both the varieties was obtained at Rahuri, where the rainfall was 618 mm. Therefore, it would appear that grain yield of pigeonpeas is not related to water availability. This could be further emphasized because the yields at Hissar, with a rainfall of 398 mm, were 1389 and 1354 kg/ha of Prabhat and T-21, respectively, whereas, at Pantnagar, with a rainfall of 1412 mm, yields were 1236 and 944 kg/ha.

If grain yield is not related to the total rainfall

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then the distribution of rainfall or temperature or soil could be the alternative factors influencing yield.

Table 1. Variation in grain yield of pigeonpeas at different locations In India.

Location	Rainfall (mm)	Yield (kg/ha) Cultivars Prabhat	T-21
Ludhiana	682	1010	1028
Delhi	1035	833	1076
Hissar	398	1389	1354
Pantnagar	1412	1236	944
Junagarh	807	1007	1806
Baroda	668	936	1640
Bangalore	492	557	502
Badnapur	1029	1218	1377
Rahuri	618	1622	2323
Gulbarga	1442	999	
Kudumiam alai	851	441	231

Experiments for Determining Water Requirements

Early-, medium-, and long-duration varieties of pigeonpea — namely, Prabhat, DL-74-1, and No. 148 — were sown in a randomized block design. Plant population densities of 16 and 32 plants/m^2 were maintained (Khanna-Chopra et al. 1979). To half the number of plots, an irrigation was given on 18 Oct 1978, about 30 days after commencement of flowering in Prabhat. This was 10 days after flowering in DL-74-1, and coincided with flowering in No. 148.

Effect of Irrigation on Biomass and Yield

The total biomass increased with increasing maturity duration of the variety (Table 2). The application of an irrigation increased dry-matter production as well as grain yield. In Prabhat, increase in dry-matter production was 51% but

Table 2. Effect of single irrigation on blomass and grain yield in three cultivars of pigeonpea at two populations.

Cultivar	Duration (days)	Days to flower	Population density/m^2	Irrigation	Biomass (t/ha)	Yield (t/ha)	Harvest index (%)
Prabhat	132	67	16	No	6.68± 0.71	1.60 + 0.20	23.95
				Yes	10.10± 1.12	3.33± 0.25	32.97
			32	No	6.90 + 0.60	1.71 + 0.17	24.78
				Yes	10.08± 0.90	3.10± 0.19	30.75
DL-74-1	150	77	16	No	9.07 ± 0.39	2.36+ 0.20	26.01
				Yes	9.76± 0.18	2.93± 0.18	30.02
			32	No	9.99± 0.70	2.56± 0.20	25.62
				Yes	15.66± 0.60	4.25± 0.30	27.13
No. 148	180	94	16	No	10.58± 0.34	2.10± 0.13	19.84
				Yes	18.94± 1.78	4.29± 0.52	22.65
				No	8.95± 0.90	1.99± 0.06	22.23
				Yes	12.92± 1.61	3.12± 0.28	24.15

increase in grain yield was 94 and 108% at population densities of 16 and 32 plants/m^2 respectively. The maximum grain yield was 3.3 metric tons (tonne)/ha. Since the grain yield increased more than dry matter, there was an increase in harvest index, which went up by 6 to 9%.

Effect on Yield Components

In cv Prabhat, yield increase due to irrigation resulted from increase in the number of pods, seeds per pod, and seed weight (Table 3). The increase in all these components was more at 16 plants/m^2 than at 32 plants/m^2 density. Seed weight was influenced most and nearly doubled due to irrigation, whereas increase in the number of grains per pod was only 20%. To what extent this relationship would be maintained if there were more grains per pod, is not known in either pigeonpea or other legumes. However, from studies in cereals it is known that in wheat, sorghum, etc., there is greater reduction in the number of grains per spike or panicle (Asana 1975), but the loss in grain weight is less. Consequently, cereal physiologists have emphasized the importance of selecting genotypes with higher grain weight. The case of pigeonpea appears altogether opposite.

Effect of Water Availability in Postf lowering Period

Passioura (1976) has shown that dry-matter production and yield in wheat are related to the amount of water utilized after anthesis. Similar observations have been made by us in wheat grown under field conditions. There was almost no information on the importance of dry-matter production after flowering in pigeonpeas. An experiment was conducted in which the influence of different amounts of water in the post-flowering period was studied. Pigeonpea was grown in cement pots — four plants to a pot — containing 90 kg of field soil. At flowering, 80 pots with uniform plants were selected and divided into two lots of 40 each. To one group no water was given until the plants showed severe wilting in the morning (Fig. 1 to 3, stressed). At this time leaf water potential of the upper leaves was -25 bars. Irrigation was resumed at this stage. Four treatments of 2, 1, 0.5, and 0.25 liter water per pot per day were maintained in 10 pots each for 45 days.

In the second group of 40 pots, the supply of differential amounts of water commenced from flowering (Fig. 1 to 3, nonstressed). Four treatments of 2, 1, 0.5, and 0.25 liter water per pot were given each day (10 pots to each treatment).

There was reduction in dry weight with the reduction in supply of water; however, there was almost no difference between 90 kg and 45 kg of water over a period of 45 days. With further reduction in water application to 22.5 kg and 11.25 kg, there was greater reduction in dry weight, but there was almost no effect on pod weight (Fig. 1). With the decreasing supply of water, there was almost no reduction in the number of pods, but the number of grains increased (Fig. 2).

As against this, the plants recovering from water stress showed a sharp decline in dry-matter production. In fact, most of the dry-matter produced during recovery and thereafter could account for grain yield. Despite stress, 77% grain yield as compared with the control was obtained with the 45 and 22.5 kg water application treatments. However, with 11.25 kg water, only 28% of the control yield was obtained (Fig. 3). An interesting feature was that the number of seeds per pod increased in unstressed treatments but decreased in plants reviving after stress.

Table 3. Effect of one irrigation on some yield characteristics in cv Prabhat at two populations.

Population density/m^2		Wt/pod (g)	100-seed wt (g)	No. seed/pod
16	Unirrigated	0.142 ±0.05	33.3 ± 2.3	2.80 ±0.12
	Irrigated	0.293 ± 0.03	61.0 ± 2.0	3.43 ± 0.08
32	Unirrigated	0.186 ±0.03	39.0 ± 2.2	2.82 ± 0.21
	irrig ated	0.251 ±0.03	54.0 ± 2.0	3.36 ±0.18

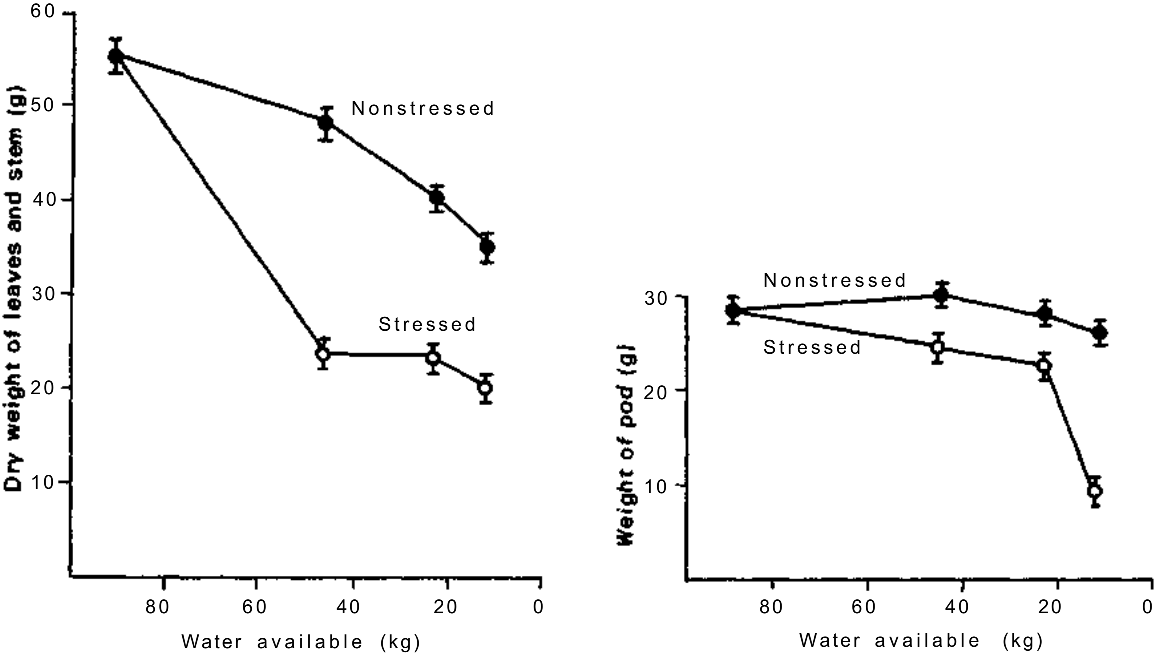

Figure 1. Effect of water availability in postflowering period on dry matter of stem and leaves and weight of pod.

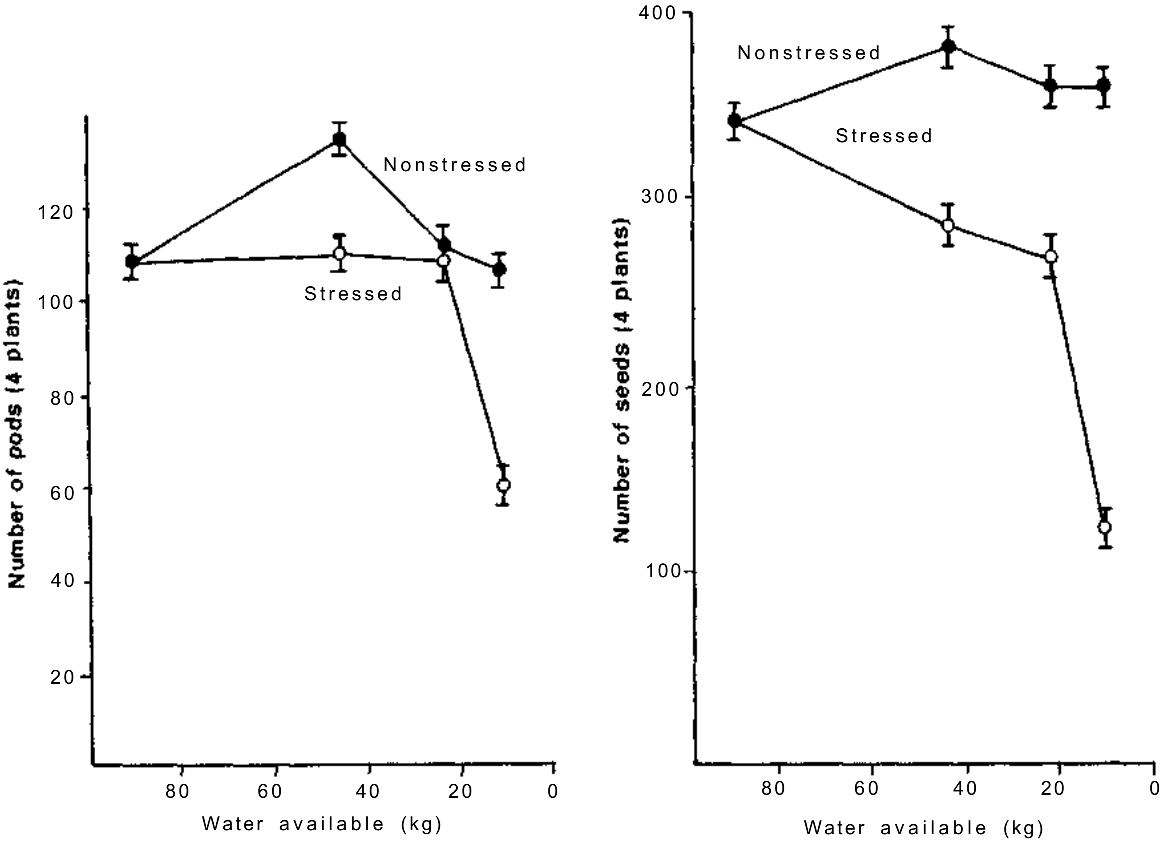

Figure 2. Effect of postllowering water availability on the number of pods and seed in pigeonpea.

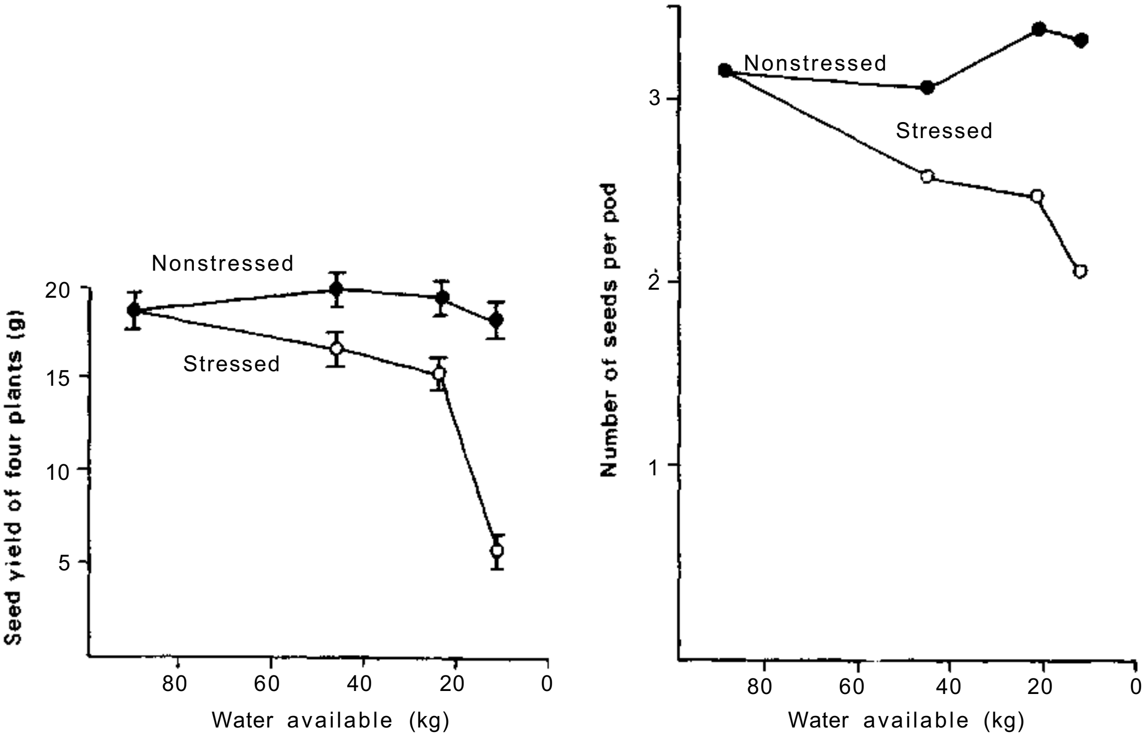

Figure 3. Effect of water availability in postflowering period on seeds per pod and seed yield in pigeonpea.

In the first place, the results indicate the importance of dry-matter accumulation after flowering. Secondly, the results also suggest the compensatory capacity of pigeonpea after stress if water is available. Nevertheless, beyond a certain limit, dry-matter is not produced with increasing water supply.

Discussion

Some of the results mentioned above indicate the behavior of the pigeonpea plant in response to water availability. However, it may be difficult to generalize these results, because two types, one with basipetal and the other with acropetal flowering, can be distinguished even among early-maturing cultivars such as Prabhat. The flowering pattern is reflected in fruit-set pattern on different branches (Fig. 4 and 5). In fact, these types could be conveniently classified as indeterminate and determinate. The hydrodynamic model suggested by Sheldrake (1978) may be partially applicable to indeterminate varieties, but it would not explain the fruit-set behavior in a determinate variety. Furthermore, even in an indeterminate variety, a few nodes do not bear any pods among the nodes that have pod-bearing branches.

A more important fact that has emerged is the failure of pigeonpea plant to control vegetative growth when more than adequate water is available. This characteristic has often not helped in increasing population density per unit area. Indeed, this characteristic is a remnant of the wild habit, because the plant had to adapt to its natural environment. However, in determinate short-duration types, this difficulty has been overcome to some extent. Further selection for this character may eventually lead to improvement of pigeonpea yield in monoculture under irrigated conditions.

Acknowledgments

I thank Dr. R. Khanna-Chopra and Dr. K. R. Koundal for their collaboration and Miss Madhu Gupta and Mr. V. S. Bhatia for their help in recording data. My thanks are also due to Dr. A. M. Michael for providing research facilities.

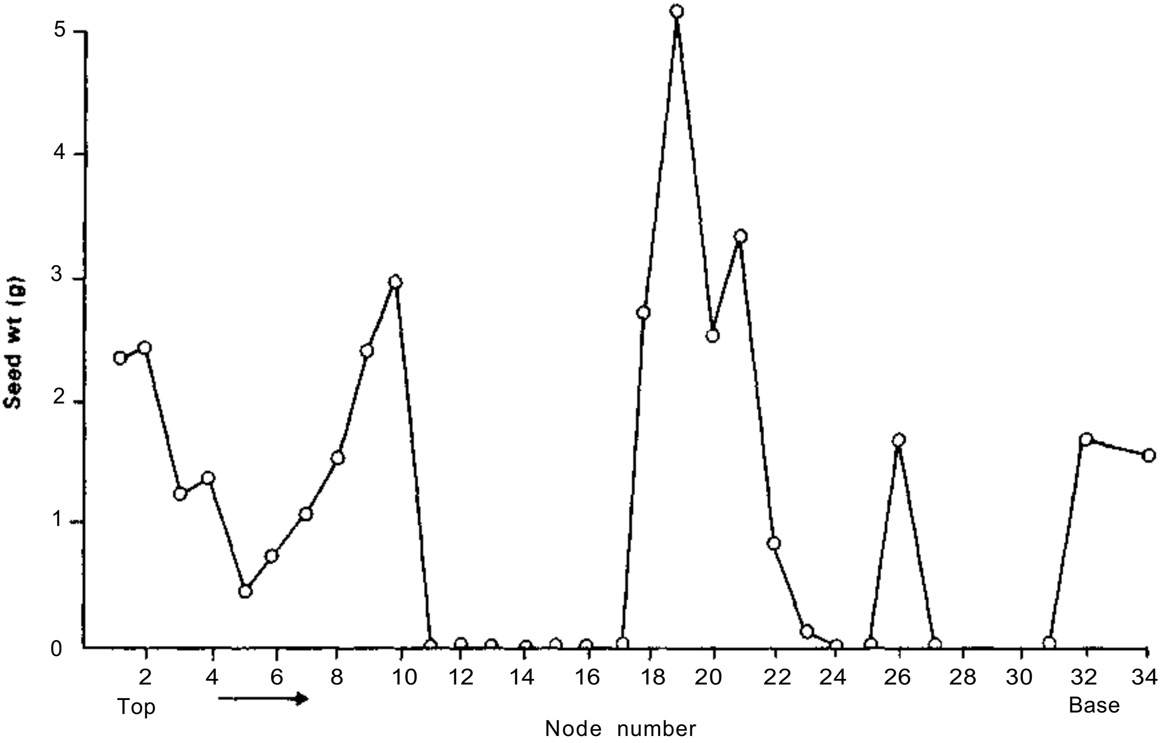

Figure 4. Nodal analysis of seed weight in cv Prabhat (determinate type).

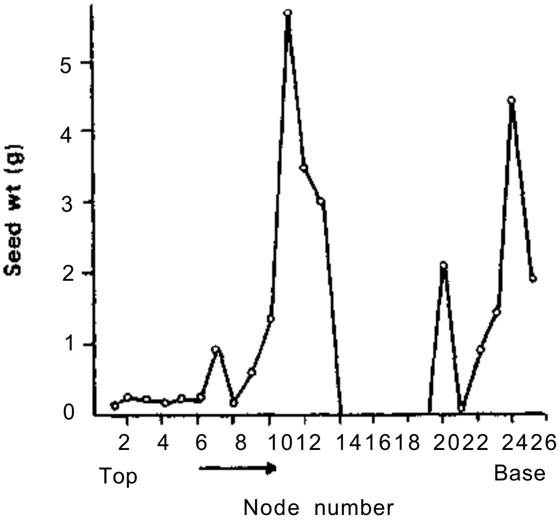

Figure 5. Nodal analysis of seed weight in cv Prabhat at harvest (indeterminate type).

References

ASANA, R. D. 1975. Physiological approaches to breeding of drought resistant crops. ICAR Technical Bulletin 52, Indian Council of Agricultural Research, New Delhi, India.

KHANNA-CHOPRA, R., KOUNDAL, K. R., and SINHA, S. K. 1979. Response of pigeonpeas to water availability. *In* Legumes in the tropics.

PASSIOURA, J. B. 1976. Physiology of grain yield in wheat growing on stored water. Australian Journal of Plant Physiology 3: 559-565.

RACHIE, K. 0., and ROBERTS, L. M. 1974. Grain legumes of the low-land tropics. Advances in Agronomy 26: 1-132.

SHELDRAKE, A. R. 1979. A hydrodynamical model of pod set in pigeonpea (*Cajanus cajan*). Indian Journal of Plant Physiology 22: 137-143.

SINHA, S. K. 1977. Food legumes: distribution, adaptability and biology of yield. Rome, Italy: FAO.

Discussion—Session 7

M. C. Saxena:

From your data on the thermal regimes and moisture availability indices for agricultural subdivisions I and III, it appears that these two factors might be responsible for the general yield differences found between these two regions. Which is the more important—MAI or temperature regime?

Virmani:

Thermal regime and water availability are two most important parameters affecting yield of pigeonpea. In Zone I and IIIb MAI is the more important of the two.

Joshi:

Agroecologically it appears that pigeonpea in north and central India needs drainage, whereas in penisular India (especially Zone IIIa) it needs soil moisture conservation by mulching or supplementary irrigation.

Secondly, we could consider changing planting geometry, adopting skip rows or paired rows to balance the plant population. Are there any advantages, under rainfed conditions, to adjusting plant population in this way?

Virmani:

We are working with the All India Coordinated Dryland Research Project on Agriculture in evaluating different methods of drainage and supplemental irrigation.

D. Sharma:

Dr. Virmani's presentation draws an interesting parallel between the agroclimatic situations of Zone II and III and those of the West African region. This shows that ICRISAT material and technology suitableto these zones worked out at Hyderabad could be transferred to the West African region. This is in line with our observations in the adaptation trials of ICRISAT. Medium-duration varieties doing well at Hyderabad were found to be very well suited to the West African countries of Mali, Upper Volta, and Ghana. With regard to the use of high plant population, we should see what happens with insect pest damage. My experience shows that thrip damage in Ghana was greater in the center of the planting than *on* the periphery, probably because thrips, which are a big problem in West Africa, thrive more under a close canopy with low light penetration.

H. P. Saxena:

Thrips have been reported responsible for pod punctures. One study has also reported that heavy infestation by thrips can cause flower drop, thus affecting pod formation. However, this should not differ so markedly from the periphery to the center of the same field. Probably water content has some bearing on insect damage. In the drier areas of Haryana and Rajasthan, for instance, borer damage is lower than in eastern Uttar Pradesh and Bihar, where soil moisture is higher.

Laxman Singh:

The growing period parameters for pigeonpea in ZoneI and II would change in off-season sowing (Sept-Oct). What are your comments?

Virmani:

The growing period has been determined by taking into consideration daily rainfall, ET, soil moisture storage capacity, and crop. The growing parameters will change in the postrainy season.

Roy Sharma:

Irrigation to pigeonpea in northern Bihar has been found to depress yield, whereas in southern Bihar, under dryland conditions, irrigation increases yield.

Farmers spade the land before starting late pigeonpea in October-November to (1) use the winter rainwater, (2) allow fallen leaves to decompose, and (3) facilitate plowing in summer after the crop is harvested. Drainage is provided during the rainy season to drain off excess water.

Joshi:

Earlier in this workshop, we heard that the April-sown crop gave very good yields and permitted a following rabi crop. Under irrigation, especially in north and northwest India, Dr. Sinha's experiment could be tested in both April-sown and June-sown conditions. Under irrigation, with and without high population density, would an acropetal flowering system be better than a basipetal one? It appears research is needed in crop geometry, skip row or paired row, as compared with solid planting. This may help in better pod setting.

Hughes:

In view of observed responses to irrigation, should simple references to the "drought tolerance" of pigeonpea be more closely defined, for instance, with respect to either plant survival or plant growth?

Sinha:

The term drought tolerance in pigeonpea refers only to survival. For obtaining a yield, water is important, particularly after flowering.

Balasubramanian:

Harvest index per se as a parameter for increasing the grain yield may be misleading at times. For example, intercropped pigeonpea had lower absolute yield but higher harvest index than sole-cropped pigeonpea. Therefore, besides harvest index, absolute yield should also be considered.

Sinha:

I agree harvest index is a parameter influenced by many factors; therefore it cannot be considered alone as the criterion. Sometimes yield improvement occurs because of improvement in dry matter.

Vijayalakshmi:

It is shown that very high populations are required (up to 600 000 plants/ha) for high yields. However, under dryland conditions. a high plateau exists for yield, and we feel lower populations may help.

Sinha:

High population density such as 400 000 to 600 000 could be useful only under irrigated conditions. In dryland soil, moisture is the factor that determines plant behavior; therefore, smaller populations would be more desirable.

Raghumurthy:

What is the total water requirement and critical stages for irrigation of pigeonpea for recommendation to command areas? Are there any studies regarding fertilizer responses with water use for maximum production?

Sinha:

Irrigation after flowering appears important for obtaining better yield. There are studies on the interaction between water and fertility but not in relation to specific stages. This possibly needs to be done.

Keatinge:

What is the optimum density recommended for irrigated pigeonpea?

Sinha:

The optimum density with current early-maturing types is probably 600 000 plants/ha.

Byth:

Dr. Sinha indicated that cv Prabhat failed to show yield response primarily because the response to irrigation was in branches that normally did not produce yield. Two factors may enter here: (1) the density was too low, since at high enough LAI, branching would not occur to any extent; (2) the timing of irrigation 30 days after flowering was too late to allow responses except in seed size. How much irrigation water was applied?

Sinha:

The data shown indicate improvement in productivity of branches and not the appearance of new branches. Approximately 6 cm of water was given during pod development.

Sheldrake:

I would like to ask Dr. Sardar Singh how the water extraction profile shown in his paper is related to root growth and distribution and also how it is related to nutrient extraction throughout the profile.

Sardar Singh:

The general agreement in the distribution of roots and the rates of the water extraction is reasonably good during the periods when the crop was not seriously stressed and the supply of water at various depths in the profile was not limiting water-uptake rates. We do not have information regarding nutrient extraction at various depths in the profile. Your suggestion is very valuable and we will look into this aspect in our current experiments with labeled nutrient.

M. C. Saxena:

Drainage is an important component in the water-balance equation and you did mention that the drainage component was quantified. Could you give us an idea of the magnitude of drainage and whether there was a difference between various treatments?

Sardar Singh:

Drainage loss constituted 15 to 23% of the total seasonal rainfall in the deep Vertisol. Computed drainage was not very different in the various crop treatments. Drainage was computed by an instantaneous overflow model using the profile storage capacity, rainfall, initial moisture content, and tensiometer data. The outflow computed as daily step function gives the correct amount of drainage but may distort the outflow rates.

M. C. Saxena:

Dr. Joshi's concern about improving the moisture situation in Zone I and III did attract attention in the AICPIP several years ago. Work on ridge planting at Delhi and Pantnagar clearly indicated that yields could be increased by improving surface drainage. Mulching with straw even late in the season showed positive responses. Regarding plant population, the optimum differed with dates of planting and plant type. With early-maturing varieties and late planting, conspicuous responses to increased plant population up to 100 plants per m^2 have been obtained.

Wallis:

As we move into higher density stands, pod number per plant decreases markedly in the center of the stand compared with the border rows. However, pod number per hectare is maintained and often increased, leading to higher yield. Additional advantages in flower synchronization and easier insect control are also gained in high population stands.

Joshi:

With top-borne pods, mechanized harvesting and better insect control, which Australia can afford, your statement would be fully valid. But my suggestion was with regard to a greater degree of soil moisture stress, high pesticide costs, which the farmer is unable to afford, and scarcely any chance of mechanized harvesting. Here the situation would be quite different.

Session 8

Seed Production

Chairman: J. M. Green

Rapporteurs: L. J. Roddy
K. C. Jain

Maintenance of Pigeonpea Cultivars

S. C. Gupta, L. J. Reddy, D. Sharma, J. M. Green, Anishetty N. Murthi, and K. B. Saxena*

Abstract

A considerable amount of outcrossing caused by insect pollinators, especially Megachile *spp., poses problems in developing pure lines and in maintaining purity of cultivars in pigeonpeas. Different methods of setting using glassine bags and two different sines of muslin cloth bags on individual plants and by using bee-proof cages on populations were studied. Based on these studies, muslin cloth bags for setting single plants and bee-proof cages for bulk setting of progenies are suggested. A modified flower character that ensures 100% self-fertilization is being transferred to widely adapted established cultivars BDN-1 and C-tt to multiply their seed under natural se/fing. Studies on yielding ability, adaptability, and stability of the inbreds indicated no adverse effects of setting. Procedures for maintenance of breeding stocks, composite populations, and newly released cultivars are suggested.*

The benefit of improved varieties cannot be realized until enough genetically pure and healthy seed can be produced to allow the new variety to be grown on a commercial scale over the entire area of its adoption. Problems in the utilization of new varieties do not end with the initial distribution of improved types to the farmers. Provision must be made to maintain varietal purity, and production of genetically pure and good quality seed is an exacting task requiring high technical skills and comparatively heavy financial investment.

The maintenance or preservation of a cultivar in its original form without deterioration of its performance over years has been the main concern of the seed industry. The causes of varietal deterioration, which the maintenance systems should guard against, have been well documented (Kadam 1942; Panse 1942; De Haan 1953; Elliott 1958; Lewis 1970; and Agarwal 1980). Some of the important ones are: mechanical mixtures; natural cross-pollination; premature release of varieties; selective influence of diseases; and gene frequency changes caused by strong genetic drift, natural selection, and mutations.

Although the floral biology of *Cajanus cajan* (L) Millsp. favors self-pollination, natural outcrossing to the extent of 3 to 40% has been reported (Sen and Sur 1964; Khan 1973). Several species of bees, in particular *Megachile* species, are the most important pollinators (Williams 1977). As a result of frequent outcrossing, existing standard adapted cultivars have become heterogeneous for several important agronomic characters, including disease resistance. Because of improper maintenance, for instance, the cultivar Bahar (No. 1258), recommended for postrainy-season planting in Bihar, has lost its resistance to sterility mosaic disease, perhaps as a result of outcrossing with susceptible cultivars. Occurrence of natural crossing poses problems in developing pure lines and in maintaining the purity of released cultivars. To overcome these problems, cross-fertilization must be prevented. This can be accomplished either by growing the strains in isolation or by covering the unopened buds to prevent bee visitation to the flowers (Ball 1912; Wilsie and Takahashi 1934; Abrams 1967). In a breeding nursery, where a large number of strains are grown together, complete isolation of strains is not possible; therefore the more laborious and expensive method of covering unopened buds with bags or cages is used.

* Pulse Improvement Program, ICRISAT.

Uniformity of breeding lines and cultivars is important for consistent performance. However, the possible effects of close inbreeding on vigor and range of adaptability should be considered for proper evaluation of the genotypes as cultivars and for repeated use as parents in the crossing program. This paper deals with our experiments on techniques of selfing to decide the best means of artificial self-pollination, and with our studies on the effects of inbreeding on adaptability and stability. Procedures for maintenance of breeding stocks, composite populations, and newly released cultivars are also suggested.

Techniques of Selfing

Bagging

Materials Used

To determine the best means of artificial self pollination, three types of bags were used at the time of flower initiation:

1. Glassine bags (13 cm x 8 cm): Ten single racemes per plant were covered with glassine bags after removing all except two unopened buds. The bags were removed after 7 days.
2. Small muslin cloth bags (60 cm x 20 cm): Two flowering branches per plant were covered separately with small muslin cloth bags.
3. Large muslin cloth bags (135 cm x 90cm): Entire plants were covered with large muslin cloth bags.
4. Control: The number of pods produced on plants left uncovered was recorded.

One hundred plants were used for each of the above treatments on two cultivars, ICP-1 and NP (WR)-15.

Comparative Costs and Returns from Bagging

A comparison of mean pod setting under three methods of selfing and open pollination in two cultivars, ICP-1 and NP (WR)-15, is given in Table 1. Under normal conditions of open-poll nation, on an average 251 and 240 pods per plant were harvested from ICP-1 and NP (WR)-15 respectively. In both the cultivars, the large cloth bags gave the maximum number of selfed pods per plant; small cloth bags came next, and glassine bags third. The reduction in pod set, when selfing with large muslin cloth bags, as compared with the control, was 16.3% in ICP-1 and 6.25% in NP (WR)-15.

The cost (including labor wages and cost of bags) of production of selfed seed was highest for glassine bags, second for small muslin cloth bags, and least for large muslin cloth bags. Although cost of selfed seed is lowest with the use of large bags to cover the entire plant, this method has the disadvantage that no observation can be recorded on the selfed plants. So, depending on the needs of the breeder, either large or small muslin bags can be used economically to get selfed seeds from individual plants.

Table 1. Number of pods produced under different methods of selfIng in two cultivars of pigeonpea.

	ICP-1				ICP-6443 NP (WR)-15			
Treatment	Total bags used	Total pods set	Av. pod set per bag	Av. pod set per plant	Total bags used	Total pods set	Av. pod sot per bag	Av. pod set per plant
Setting with								
Glassine bags (13 cm x 8 cm)	1000	245	0.245	2.45	1000	878	0.878	8.78
Small muslin cloth bags (60 cm x 20 cm)	200	3 150	15.75	31.50	200	3 490	17.45	34.90
Large muslin cloth bags (135 cm x 90 cm)	100	20 900	209.00	209.00	100	22 500	225.00	225.00
Open-pollination (unselfed plants)		25 100		251.00		24 000		240.00

Bee-proof Cages

Materials Used

To study the feasibility of using bee-proof cages in producing selfed pigeonpea seeds, five F_2 populations were planted in eight-row plots and in each F2, four rows were covered with a wire-mesh cage just before flowering. Data were recorded on the average number of healthy, damaged, and total pods per plant and yield of 50 random plants in each of the F2 populations, both inside and outside cages.

Comparison with Bagging

Data average number of healthy, damaged, and total pods per plant and yield of 50 plants in different F2 populations both inside and outside bee-proof cages are summarized in Table 2. The number of damaged and total pods per plant was greater outside the cage than inside in all five populations. However, theyield of 50 plants was more inside the cage in all the populations except in cross ICP-3783 x ICP-6929. The higher yield inside the cages appears to be due to reduced insect damage to the pods. These observations suggest that in spite of the reduced pod set, production of selfed seed under cages is satisfactory.

Rough estimates of comparative costs indicate that the material cost of cages is four times higher than that of cloth bags. However, in view of the reduced labor costs and reusability of cages, bee-proof cages are to be preferred over cloth bags for bulk selfing of progenies. Delayed planting to reduce height of the progenies will further enhance the usage of reasonably small cages. Similar bee-proof cages have been successfully used in maintaining pure lines of cotton (Ball 1912).

Use of Modified Floral Morphology

Another way to overcome the problem of natural outcrossing is to look for some characters that ensure 100% self-pollination. In normal pigeonpeas, flower-opening takes place the day after the anthesis. A derivative from *Cajanus cajan* (cv T-21) x *Atylosia lineata,* where flower opening has been considerably delayed after anthesis, has been identified. Due to this modification in floral biology, 100% selfing is ensured (detailed information to be published separately). For practical application in seed production, this character is being transferred to established and widely recommended cultivars, BDN-1 and C-11.

Effects of Inbreeding

Effects on Yield of Pure Lines

To determine the effect of inbreeding on grain yield, six adapted early-maturing cultivars — Pant A-3, Prabhat, Pant A-2, UPAS-120, T-21, and Pusa Ageti—were purified by selfing single-plant progenies for four generations. The range and mean of seed size and yield of open-pollinated original cultivars and those of the derived selfed lines were compared in replicated tests conducted at our Hissar subcenter.

Seed size and yield of six inbred lines and their respective open-pollinated cultivars

Table 2. Intensity of insect damage and yield inside and outside bee-proof cage in five Ft populations.

Populations	Average number of pods/plant[a]						Yield of 50 plants(g)	
	Healthy		Insect damaged		Total			
	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
ICP-3783 x ICP-6929	13.5	7.7	8.5	29.3	22.0	37.0	174.4	195.3
ICP-7118 x ICP-6907	12.2	9.3	11.0	25.1	23.2	34.4	222.4	124.2
ICP-7118 x ICP-7336	18.6	9.0	5.5	21.4	24.2	30.3	168.8	146.2
ICP-3783 x ICP-6909	6.4	1.2	9.6	18.8	16.0	20.0	155.4	63.0
ICP-7035 x ICP-7183	8.2	4.5	6.8	16.8	15.0	21.2	219.1	62.4

a. Average Is based on 50 random plants.

grown at Hissar are given in Table 3. Distribution of yields of derived inbred lines of six cultivars in relation to the check cultivar are shown in Figure 1. In all cultivars except Pant A-3, differences among entries were significant for seed size. Two inbred lines in each of Prabhat, UPAS-120, and Pusa Ageti were significantly higher yielding than their respective check parents. It is evident from both Table 3 and Figure 1 that in all the tests the mean yield of the inbred lines was close to that of their respective open-pollinated parents, indicating that in general there was no yield depression resulting from selfing these open-pollinated cultivars.

Effects on Adaptability and Stability

Tostudy the adaptability and relative stability of the inbred lines, two inbred lines each of T-21 and Pusa Ageti were entered in ACT-1 of the All India Coordinated Pulse Improvement Project and their yields were recorded at six locations in India.

The yields of two inbred lines each of T-21 and Pusa Ageti at six different locations in India are. given in Table 4. Unfortunately, the open-pollinated source cultivar, Pusa Ageti, was not included in these tests. However, the yield data on cv T-21 and its inbred lines indicated that the inbred lines are somewhat superior in performance to their source cultivar. The percent coefficients of variability for both the pure lines ICPL-5 and ICPL-6 of T-21 are comparatively less than the check cultivar (Table 4). Their percent CVs and yield performance across locations indicated improved adaptability and stability of the inbred lines.

Tabic 3. Seed size and yield of check and Inbred linas of pigaonpaa In various tests.

Cultivar	No. of inbred lines tested	100-seed wt (g) Inbred lines Range	Mean	Check[a]	LSD (5%)	Yield (kg/ha) Inbred lines Range	Mean	Check[a]	LSD (5%)	No. of lines significantly better than the check
Pant A-3	18	8.14- 9.93	9.00	8.75	NS	1050- 1607	1333.8	1111.1	NS	
Prabhat	20	6.05- 7.17	6.51	6.16	0.28	1163- 1739	1429.6	1416.2	259.1	2
Pant A-2	24	6.97- 9.25	8.25	6.77	0.57	1259- 1880	1565.5	1705.6	376.8	
UPAS-120	18	7.06- 9.26	7.65	7.13	0.42	1238- 2396	1885.1	1803.6	521.8	2
T-21	13	6.82- 8.84	7.56	7.46	0.81	1659- 2184	1901.0	1834.8	NS	
Pusa Ageti	24	9.32- 10.51	9.98	10.11	0.60	493- 1644	1128.7	1025.9	491.7	2

a. Open-pollinated source cultivar.

Table 4. Yield performance of Inbred lines of T-21 and Pusa Ageti in ACT-1 at different locations in India, 1978-79.

ICPL No.	Source pedigree	Yield (kg/ha) at Badnapur	Akola	Baroda	Junagadh	Rahuri	Varanasi	Mean	CV(%)
5	T-21	548	200	1168	879	1303	477	762.5	56.07
6	T-21	782	179	1156	708	1399	499	787.2	55.94
	T-21 (check)	526	195	1103		1163	333	664.0	66.94
7	Pusa Ageti	513	237	985	907	1105	155	650.3	62.26
8	Pusa Ageti	550	220	1092	630	1177	144	635.5	67.61

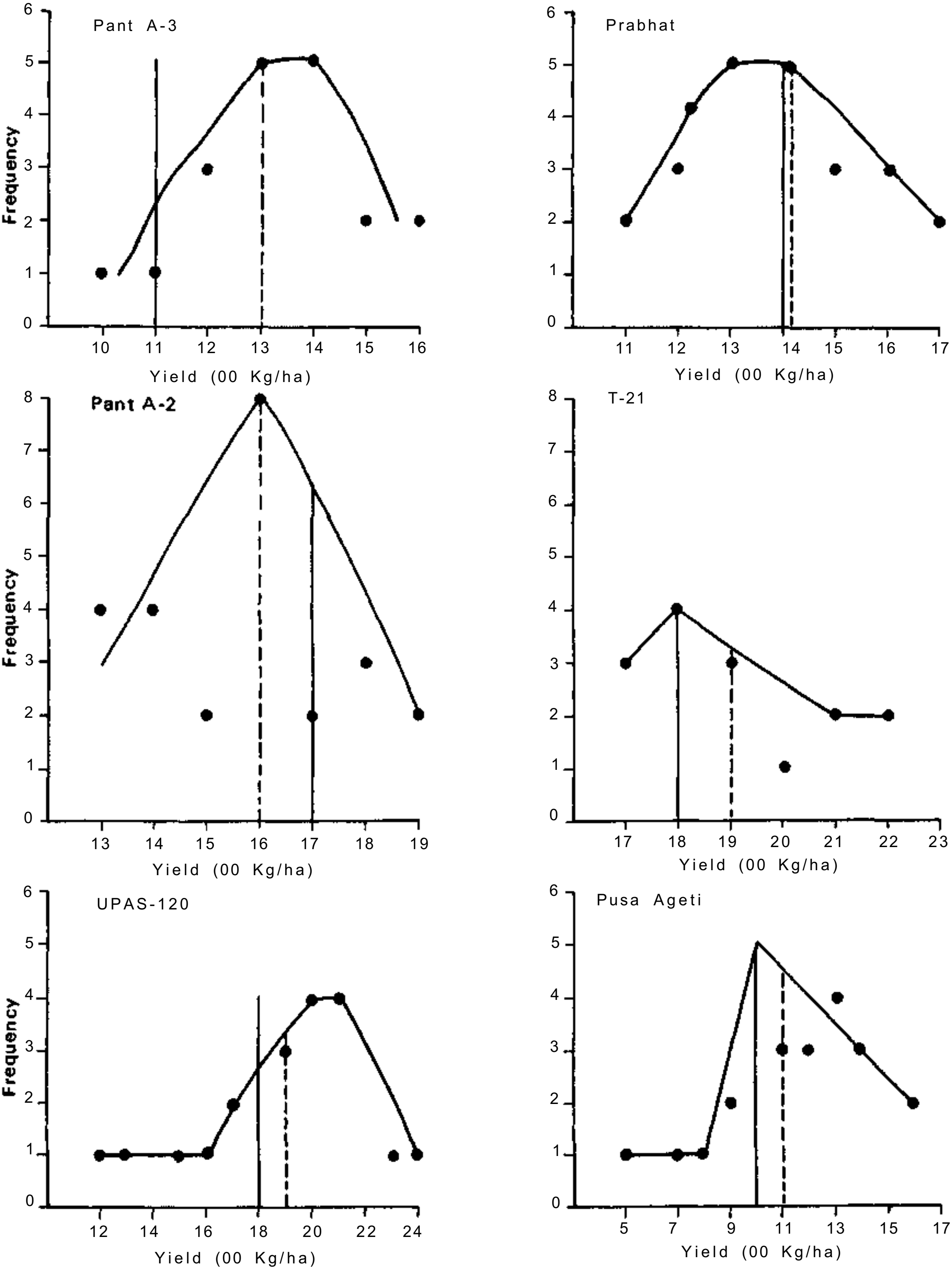

Figure 1. Distribution of yields of derived inbred lines of six cultivars in relation to the check cultivar.

Procedures for Maintaining Varieties

Pigeonpea breeders often resort to plant and progeny selection under open pollination and subsequently bulk progenies as cultivars. This results in considerable heterogeneity in the cultivars (Fig. 2). Several authors (De Haan 1953; Lewis 1970; Agarwal 1980) have reviewed the various systems of maintaining varieties and the complexity of most of the systems reviewed indicates the desirability of releasing stable varieties. Different maintenance and purification procedures for promising breeding stocks, composite populations, and newly released cultivars of pigeonpea are discussed below.

Figure 2. Selfed vs open-pollinated (O.P) progenies of a determinate cultivar. See off-types (arrows) in the open-pollinated progenies.

Promising Breeding Stocks

New germplasm collections, lines, or selections that give highly promising performance in breeding nurseries and station trials should be considered for purification. In the station yield tests, about 100 good and healthy plants in the border rows of each new promising strain should be selfed. The selfed seed of the plants taken from promising strains should be kept for growing single-plant progenies. The following year, from about 20 selected progeny rows, 5 to 10 plants should be selfed for the next cycle of plant to progeny row. After three generations of plant-to-progeny-row selfing, part of the seed may be bulked for coordinated multilocation yield testing and part for further purification, maintenance, and improvement.

For the purpose of purifying and maintaining a particular strain, the initial handful of seed obtained from selected individual plants can be used by the breeder. Its further multiplication under his supervision will provide breeders' seed, and this constitutes the source for all further seed production. The varietal purity of subsequently multiplied foundation, registered, or certified seed depends largely upon the quality of the breeders' seed. Unless the breeders' seed or nucleus seed is of the highest purity and quality, the seed multiplied from it cannot be regarded as of satisfactory genetic purity.

Composite Populations

In order to promote genetic recombination utilizing natural cross-pollination, the composite populations should be maintained by growing the population in isolation of at least 100 m. If isolation of 100 m is not feasible, composite populations may be maintained at the cost of sacrificing 14 m of crop used as a barrier strip. Ariyanayagam (1976) stated that pollinators tend to restrict their foraging activity to an area not too distant from the point of commencement. Once they land on a chosen spot, their subsequent progress from flower to flower in search of pollen and nectar is by short flights. As the distance from initial halt increases and, consequently the number of flowers visited increases, pollen initially gathered would tend to get diluted or masked by more recent acquisitions. Therefore, with increasing distance, outcrossing from an initial source would tend to decrease.

Newly Released Cultivars

Turner (1963) reported a pedigree system for maintaining a variety of cotton, a crop in which the proportion of self- and cross-pollination is very similar to that of pigeonpea. Each year progeny rows were grown from single-plant selections made in the previous year. Single-plant selections were made to provide seeds for the prongeny-row nursery the following year. From within the better progeny rows, additional single-plant selections were made. Open-pollinated seeds from selected plants were bulked to provide seed for a family test. Selfed seed was bulked to plant isolated increase blocks for the production of breeders' seed. During the 1975 Kharif Pulses Workshop held in New Delhi, it was suggested that breeders should grow a population of about 10 000 plants at an isolation distance of at least 100 m. They should select and grow 1000 single-plant progenies and finally they should bulk on the basis of progeny performance. Roguing by itself is not sufficient to prevent deterioration, since only types differing from the strain in broad morphological features can be removed by this means, and no check on quantitative characters such as yield is possible. Therefore, progeny testing is essential, as most of the distinguishing characters are quantitative and only progeny testing will ensure the genetic purity of genotype.

For the initial stage of multiplication, the use of pedigree seed is desirable. Each year 100 to 200 single-plant progeny rows should be grown from selfed seed of single-plant selections made in the previous year. From within the uniform progeny rows, 5 to 10 plants should be selected and selfed. Thus selection is practiced both between progeny rows and between plants within progenies. This process should be repeated every year. For the multiplication of breeders' seed part of the selfed seed should be bulked from the uniform and true-to-type lines based on progeny performance.

Seed Storage System

For maintaining cotton varieties, Lewis (1970) suggested that at the final stage of the establishment of a variety a large lot of seed be stored in environmentally controlled storage rooms. This system requires an estimate of both the amount of breeders' seed needed each year and the number of years the variety can be maintained under these storage conditions. If enough genetically pure base seed is available and cold storage facilities exist, then this system will reducethe labor and trouble of growing out single-plant progenies every year. The seed storage system guards effectively against all the causes of varietal deterioration, as stored seed would not be exposed further to mechanical mixtures or to natural outcrossing. Since the breeder could be surethatthe variety would not deteriorate, he could spend more time in breeding a new variety rather than spending time and money in maintaining the existing one. However, further improvement of the cultivar is not possible in this system of maintenance.

Conclusion

Varietal maintenance is concerned with keeping a continuing supply of genetically pure breeders' seed available. Uniformity of cultivars is important for consistent performance over years and locations. The considerable amount of outcrossing found in pigeonpea poses problems in developing pure lines and in maintaining purity of cultivars. Mixtures resulting from outcrossing can be prevented either by growing genetically pure cultivars in isolation or by covering flowering branches with muslin cloth bags to prevent bee visitation. Studies have indicated that the yield, adaptability, and stability of some cultivars were not affected adversely by inbreeding. Procedures for maintaining promising breeding lines, composite populations, and newly released cultivars have been discussed. It has been suggested that the promising breeding lines be entered in coordinated multilocation yield tests only after at least three generations of plant-to-progeny-row selfing.

References

ABRAMS, R. 1967. Studies on natural cross-pollination in pigeonpea (*Cajanus cajan*). Journal of Agriculture of the University of Puerto Rico 51(1): 1-4.

AGARWAL, R. L. 1980. Seed technology, New Delhi, India: Oxford and India Book House. 685 pp.

ARIYANAYAGAM, R. P. 1976. Outcrossing and isolation in pigeonpeas. Tropical Grain Legume Bulletin 5: 14-17.

BALL, W. L. 1912. The cotton plant in Egypt. London: Macmillan.

De HAAN, H. 1953. Maintaining varieties of self-fertilized crop plants. Euphytica 2: 37-45.

ELLIOTT, F. C. 1958. Plant breeding and cytogenetics. New York: McGraw Hill.

KADAM, B. S. 1942. Deterioration of varieties of crops and the task of the plant breeder. Indian Journal of Genetics and Plant Breeding 2: 159-172.

KHAN, T. N. 1973. A new approach to the breeding of pigeonpea (*Cajanus cajan* Millsp.). Formation of composites. Euphytica 22: 373-377.

LEWIS, C. F. 1970. Concepts of varietal maintenance in cotton. Cotton Growing Review. 47: 272-284.

PANSE, V. G. 1942. Methods in plant breeding. Indian Journal of Genetics7 and Plant Breeding. 2:151-158.

SEN, S. K., and SUR, S. C, 1964. A study on vicinism in pigeonpea (*Cajanus cajan* [L.] Millsp.). Agricultura Louvain 12: 421-426.

WILLIAMS, I. H. 1977. Behaviour of insects foraging on pigeonpea *(Cajanus cajan* [L.] Millsp.) in India. Tropical Agriculture (Trinidad & Tobago) 54(4): 353-363.

WILSIE, C. P., and TAKAHASHI, M. 1934. Natural crossing in the pigeonpea. Journal of Agricultural Research 49(10):923-927.

TURNER, J. H. 1963. Breeding methods used in maintenance and improvement of Acala 4-42 variety of cotton. Pages 34-51 *in* USDA ARS Cotton Research Station Report, Shafter, Calif, USA.

Pigeonpea Seed Production under the National and State Seeds Corporations

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Abstract

Pigeonpea is the second most important source of pulse protein for the population of India, and increasing pigeonpea production is an important component of the strategy for increasing availability of pulses. But shortage of quality seed is a major constraint. Existing institutions such as the National and State Seeds Corporations can meet the seed requirements, provided they are given appropriate incentives and support. These include a flexible subsidy to cover the difference between the cost of seed and the price at which the seed can be actually marketed, for both certified and truthfully labeled seed; a scheme to compensate seed growers for carryover losses; and certain changes in existing regulations imposed by certification agencies.

In India pulses form the only source of protein for a large section of the population; however, the availability of pulses has been declining over the last few years, because, on the one hand, the population has increased steadily; on the other, pulse production has remained more orless stagnant. Thus, the per capita availability of pulses per year declined from 27.5 kg in 1959 to a mere 16 kg in 1979. The optimum requirement per capita per annum has been estimated to be around 23.5 kg. Of late, high priority has been accorded to increasing pulse production in the country.

The total production of food grains in the country has risen significantly over the last two or three decades, but this rise has come mainly from cereals, particularly wheat and rice. The average annual production of cereals during the 5-year period 1950-51 to 1954-55 was 50.49 million metric tons (tonnes); in the period 1975-76 to 1977-78, it rose to 107.60 million tonnes. The corresponding figures for pulses are 9.51 and 12.10 million tonnes. Average yields show a similar trend: the average yield of sorghum rose from 427 kg/ha in 1950-55 to 662 kg/ha in 1977-78; pearl millet, from 304 to 490 kg/ha. However, in the same span, pulse yields rose from 468 kg/ha to only 509 kg/ha.

The National Workshop on Development of Action Plan for Increasing Production of Pulses and Oilseeds, held at IARI in 1979, identified nonavailability of quality seed as a major constraint to increasing production of pulses.

The Task Force on pulses pointed out the difficulties caused by shortage of good seed. The state seed corporations are reluctant to multiply pulse crop seed, as this is a risky venture, with low returns; these agencies prefer to multiply cereal seed, which is easy to market and very profitable.

The Task Force recommended that the state and national seed corporations begin multiplication of pulse seed and that this seed be sold at a rate about 20% higher than the prevailing market price of the grain. Subsidies to encourage farmers to buy good seed were also recommended.

Pulse crops collectively occupied an area of around 24 million ha in the country in 1977-78. Of this, 8.3 million ha were under chickpea, with a production of 4.6 million tonnes; 2.6 million ha under pigeonpea, with a production of 1.6 million tonnes. Average yields were 661 kg/ha for chickpea and 720 kg/ha for pigeonpea. For these reasons, the main thrust of the country's pulse production program is on chickpea, pigeonpea, urd bean, and mung bean. Adequate availability of pigeonpea seeds thus assumes importance.

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The problems of seed production of pigeonpea are similar to those of other pulses. However, one important difference arises because the pigeonpea cultivars available today are of long duration.

While commercial pulse crops are mostly grown under dryland conditions, seed crops are mostly taken under irrigated conditions. If the pigeonpea seed crop is to be grown under irrigated conditions, the seed grower farmer has to forego his second crop; therefore he must be compensated by way of higher prices for his produce.

Scientific Seed Production in India

Let us look briefly at the history of scientific seed production in the country and the evolution of the institutional setup to examine its adequacy for pulse seed production. Seed production on sound scientific lines started in the country in the early 1960s, when the National Seeds Corporation (NSC) was set up in 1963. This corporation, which is a fully owned company of the Government of India, played a pioneering role in establishing a system of seed production through contract growers and in evolving standards for seed production and certification. For some years, the NSC was the only significant seed-producing agency in the country. In 1969 the Tarai Development Corporation (TDC) was set up with the assistance of the World Bank. In the meantime, private parties also began establishing seed companies, particularly in Maharashtra, Karnataka, Tamil Nadu, and Andhra Pradesh.

A major development took place with the formulation and implementation of the National Seeds Programme (NSP) in 1975-76. Under this program, nine State Seeds Corporations (SSCs) have been set up in Punjab, Haryana, Maharashtra, Andhra Pradesh, Rajasthan, Uttar Pradesh, Karnataka, Bihar, and Orissa. State Seeds Corporations have been set up in Assam and Gujarat also, though not under the NSP, and are planned for West Bengal and Madhya Pradesh also.

The National Seeds Programme attempts to take an integrated approach to seed development in the country. In formulating it, the experience of the working of the NSC and the TDC has been fully taken into account as also the wide-ranging recommendations of the Seed Review Team and the National Commission on Agriculture. Under this program the responsibilities of various agencies concerned with seed development have been spelled out, and provisions made to strengthen the facilities required by each agency to discharge its responsibility.

Breeders' Seed

The responsibility for production of breeders' seed is vested in the ICAR institutes and the state agricultural universities. The NSC, which has been charged with the responsibility of meeting the national demand for foundation seed of all-India varieties, assesses the requirement of breeders' seed and places an indent on the ICAR. The ICAR, through the crop coordinators, allocates the production programs to the various agricultural universities and the ICAR institutions, which produce and deliver the breeders' seed to the NSC.

Foundation Seed

The breeders' seed thus made available is then multiplied into foundation seed by the NSC through the agricultural universities and other agencies like the State Farms Corporation of India. Where these agencies cannot produce foundation seed, the NSC organizes supplemental production through farmers.

Certified Seed

The State Seeds Corporations are expected to produce certified seed only. They and other seed-growing agencies in the private and public sectors place indents with and get the foundation seed from the NSC for certified seed production. The NSC also produces certified seed to supplement the production of the SSCs.

Most of the seed produced by the SSCs and the NSC is certified under the Seeds Act, 1966. For this purpose, independent State Seed Certification Agencies have been set up in almost all states where seed production programs exist.

The certified seed produced by the SSCs and the NSC is marketed through a variety of channels. These include private retailers, cooperative societies, agroservice centers, and extension agencies. The marketing activities of the SSCs are confined to theirown states. Interstate marketing of seeds produced by the SSCs is through the NSC.

Reasons for Low Production

Until recently, seed production in both the public and private sectors was mostly of the major cereal crops, vegetables, and fiber crops like cotton and jute. The comparative figures of cereal seed production and pulse seed production of the NSC, TDC, and SSCs illustrate this (Table 1).

There are three main reasons for this. The thrust of the governmental programs for increased food production was, until recently, on cereals. As a result, certified seed production of crops other than cereals were given comparatively low priority. Secondly, seed grown, inspected at field stage, and graded, treated, packed, and stored under controlled conditions is more expensive than the planting material that the farmer sets aside from his produce or what goes in farmer-to-farmer exchange. The costlier seed produced along proper scientific lines will not be purchased by the farmers unless it is of demonstrably superior varieties. The kind of breakthrough that has taken place in cereals and some other crops is yet to take place in pulse crops; short-duration pigeonpea varieties, for instance, have been evolved and released only very recently. Thirdly, pulses are primarily grown under unirrigated conditions. Out of the total area of about24 million ha under pulses, only about 1.9 million are under irrigation; pulse seed production, therefore, is risky.

Risks Involved in Pulse Seed Production

To cover the risks, the growers must be compensated by way of attractive procurement prices. The NSC experience has been that unless a mix of minimum guaranteed price and market linked procurement price is offered, the growers are tempted to sell off their produce as grain. At these remunerative procurement prices, the price of processed, bagged, and tagged certified seed will become so high that without a subsidy the seed will not sell. It is only

Table 1. Seed production (00 kg) by the National and State Seeds Corporations.

Organization	Crop	Quantities of certified seed produced in different years					
		1973-74	1974-75	1975-76	1976-77	1977-78	1978-79
NSC	Cereals	162 343	695 183	529 870	217 521	260 800	294818
	Pulses	1912	2631	3 751	272	3 218	2 760
TDC	Cereals	205 690	302 200	321270	243 310	25 000	293 193
	Pulses						985
PSSC	Cereals				51000	129 096	60 000
	Pulses					388	746
HSDC	Cereals				97 722	103 354	93 800
	Pulses					14 479	5500
MSSC	Cereals					24 825	21940
	Pulses						
RSSC	Cereals						93 800
	Pulses						5 500
KSSC	Cereals						10 867
	Pulses						1625

TDC =Tarai Development Corporation
PSSC = Punjab State Seeds Corporation
HSDC = Haryana Seed Development Corporation
MSSC = Maharashtra State Seed Corporation
RSSC = Rejasthan State Seeds Corporation
KSSC = Karnataka State Seeds Corporation

since 1977-78 that the Government of India has begun to implement the present subsidy scheme, because the absence of a subsidy had acted as a deterrent to pulse seed production in the past.

Expansion of Pulse Seed Production

In the past, production of certified pulse seed was done almost entirely by public sector organizations. The marketing also has been almost entirely through public sector agencies, and this is likely to be the trend in the future also. The NSC and the State Seeds Corporations will be expected to produce most of the seeds required to support the governmental programs of increased production of pulses. The infrastructural and institutional arrangements existing today will need no changes for meeting this challenge.

The Government of India program envisages a step-up in the production of pulses to 15.5 million tonnes by 1983; of this, the share of pigeonpea is expected to be 2.5 million tonnes. The strategy for pigeonpea will be to increase the area by 0.3 million ha under irrigation, changing of cropping pattern from maize-wheat to pigeonpea-wheat in states like Punjab, Haryana, and Uttar Pradesh, and growing of short-duration varieties of pigeonpea extensively.

The Crops Division of the Ministry of Agriculture has estimated that the certified seed support required for this should be to the extent of 2% of the total requirement of planting material. Thus for the increased area of 2.9 million ha under pigeonpea, the certified seed support should be of the order of 580 000 kg. Production of certified seed of pigeonpea to this extent is quite within the competence of the NSC and the SSCs.

Marketing

Marketing of this quantity of seed without a subsidy will, however, be difficult. At the procurement prices that the seed-producing agencies will have to pay to the seed grower, the sale price of certified seed will be quite high. For example, NSC's procurement price for the seed grower-farmer today is Rs 420/100 kg of graded pigeonpea seed. At this price, the final sale price of certified seed cannot be less than Rs 700/100 kg. The seed user-farmer will not be inclined to purchase the seed at these prices; hence the need for subsidy.

Pricing and Subsidies

Under the present scheme of subsidy, the Government of India fixes what the ultimate sale price should be. The market price of grain is taken into account and the certified seed price is fixed at a level 20% above this, so that, on the one hand, the price is not too prohibitive and, on the other, the danger of the seed being used as food is minimized. The public sector seed-producing agencies or the state governments are then given a subsidy of Rs 150/100 kg if the seed is sold to the consumers at the price fixed by the Government. As for pigeonpea, the current sale price fixed by the Government of India is Rs 550/100 kg, taking into account the cost of certified seed produced by the NSC as Rs. 700.

Need for Flexible Subsidy

The subsidy being given by the Government is intended to cover the difference between the actual cost of seed and the lower price at which it becomes marketable. In the existing system, the subsidy is a fixed amount per quintal of seed. While this may work in some cases, the prevailing market prices of the grain may be so low as to necessitate a higher subsidy. It may also happen that the market price of the grain may be high enough to warrant no subsidy. Thus a flexible quantum of subsidy appears to be more desirable than the present system of a fixed subsidy.

Compensation for Unsold Stocks

While a subsidy will ensure that a seed-producing organization will not incur loss on any quantity of seed sold, there is nothing to compensate losses on unsold seed. Our experience in production and marketing of pulse seed today is so limited that the seed producers have no basis for assessing realistically the demand for quality seed, except the targets for seed distribution set by the state governments. It has been the experience of many SSCs and the NSC that seed produced on this basis is often left unsold. It is necessary that a scheme be implemented to compensate seed producers for losses incurred on unsold stocks. This is particularly necessary with pulses, because of their high protein content which makes them highly vulnerable to storage pests and leads to substantial carryover losses.

The Government of India is implementing a reserve stock scheme for seed today. Under this scheme, which is operated through the NSC, carryover losses on certified and foundation seed are compensated to some extent. This scheme, however, covers only the five cereal crops of wheat, paddy, maize, sorghum, and pearl millet at present. It is necessary to extend this scheme to pulse seed also, so that the seed-producing agencies can boldly undertake certified seed production to support the ambitious pulse production programs.

Extension Support

Extension support from the governmental agencies is extremely important. If this is not forthcoming, the seed produced at high cost can go waste. It has been the recent experience of the NSC and some SSCs that some certified seed had to be sold as grain for lack of demand, as a result of inadequate support from the extension agencies. It is hoped that with the new emphasis on stepping up pulse seed production, extension support will also be stepped up-

Other Factors Hampering Seed Production

There are certain other factors that hinder production of certified seed. One is that the present scheme of subsidy covers only certified seed, i.e., seed certified under the Seeds Act by the statutory agency. According to Section 9 of the Seeds Act, only those varieties notified under Section 5, are eligible for certification. For various reasons, many varieties of pulses today are still not notified, for example, pigeonpea cvs Sharda and Mukta. Until these are notified, certified seed production is not possible and thus seed of these cultivars will not be entitled to subsidy. It is also necessary that for some time truthfully labeled seed of these cultivars should also be considered entitled to subsidy. This matter is under consideration by the Government of India.

To enable large-scale production of certified seed, certain restrictions imposed by the seed certification agencies should be relaxed. Some certification agencies today insist that *to be* accepted for certification a seed producer should put at least 5 ha under the seed crop either himself or in association with others within a radius of 1 km. Such a restriction is a great disincentive for seed grower-farmers who are willing to try pulse seed production. Similarly, intercropping in seed production is not often allowed, even in cases when the other crop is in no way likely to affect the seed crop. Again, raising foundation seed from foundation seed of pulse crops is also not commonly permitted. This leads to shortage of foundation seed. These restrictions are currently under review by the Government of India and are expected to be revised to enable larger production of certified seeds of pulses.

Commercialization of Planting Seed

B. R. Barwale*

Abstract

The seed industry in India is barely 20 years old, but it has made tremendous strides in that time. Today it handles over 10 000 tonnes hybrid jowar, 15 000 tonnes hybrid bajra, and large quantities of hybrid maize, wheat, and paddy. The success of the hybrid cotton seed industry — producing over 2 million kg F_1 hybrid seed by hand emasculation and hand pollination — is unprecedented. Formulation of clear-cut policies will help further the growth of the Indian seed industry and provide enough quality seed to support the expanded pulse production schemes in the country.

Commercialization of agricultural crop seed began in India in 1961, with the release of the first maize hybrid. The first prerequisite for commercial seed production is the development of adaptable varieties or hybrids that are higher yielding than traditional varieties. Research and development in breeding new varieties and hybrids should keep up a steady pace to sustain viable commercial seed enterprises.

In India, the beginning made with the maize hybrids was followed by the release of the first jowar hybrids in 1964and thefirst bajra hybrids in 1965, opening the way for commercial production of agricultural seed.

Such production involves four major steps:

- Seed production
- Seed processing
- Seed warehousing
- Seed marketing

Other important related aspects are government policies, regulatory activity, quality control, and financing.

Seed Production

Breeders' Seed

Seed production starts with the production of breeders' seed, which is basically the responsibility of the breeders at agricultural universities, research institutes, or private seed companies.

Breeders' seed should be genetically pure and is supposed to be grown directly under the supervision of the breeder, who may grow any number of generations of it under his own or his nominated associates' direct supervision.

Foundation Seed

The breeders' seed is used to produce foundation seed, eligible to be certified by the official certification agency. There is a growing awareness and concern about the quality of the foundation seed among seedsmen in India. Standards have been prescribed for certification of this class of seed and all seed certified as foundation seed must meet the field standards for genetic and physical purity and viability. Foundation seed is multiplied by several agencies, such as the universities, the National Seeds Corporation, State Seeds Corporations, and private companies.

Certified Seed

From the certified foundation seed, certified truthfully labeled seed is produced by private companies or government agencies. At present, the major crops for which certified seed is produced are maize, jowar, bajra, wheat, paddy, and cotton.

The seed agencies often contract with selected farmers who have fertile land and adequate facilities for irrigation, pest control, etc., to produce the seed at a predetermined price,

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under the agency's guidance. Thousands of farmers have been so trained to plant the foundation seed provided by the agencies at the appropriate time in the desired manner. Our experience is that these farmers gain expertise rapidly and are able to produce record yields of quality seed. As much as 3750 kg/ha of jowar, 2500 kg/ha bajra, 6250 kg/ha maize, and 3750 kg/ha hybrid cotton have been harvested; unfortunately, however, the averages are still far below the highest yields obtained.

The seed is bulk-packed and brought to designated collection centers from where it is transported directly to the processing plants.

Seed Processing

Seed processing is an essential operation for conditioning and selecting seed for marketing. Where favorable weather conditions prevail, seed drying is done in the field or at the harvesting yards by the growers themselves. Almost no large-scale drying needs to be done for seed of major crops grown in the drier zones of India or during dry periods.

Seed processing generally consists of precleaning, polishing, cleaning, aspirating, gravity separation, cylinder separation, treatment with chemicals, and packaging. The basic objective is to eliminate substandard or damaged seed and seed of other crops or weeds, and to remove other foreign matter. Several sophisticated processing plants have now been established in India, with a processing capacity of up to 5 tonnes/hour.

Quality Control and Seed Certification

Under the Seeds Act of 1966, seed certification is voluntary. Certification provides an independent guarantee of minimum quality to the purchaser. Beginning with certified foundation seed, the prerequisites for seed certification involve field inspection, inspection at harvest, supervision and inspection at the processing plant, and seed testing at official laboratories. In the case of hand-emasculated, hand-pollinated crops such as hybrid cotton, field testing of seed is also required. Generally, international standards of seed certification and testing have been adopted, and most large companies and corporations have their own quality control organization to keep a consistent check on the fields and on the harvesting and processing of the seed. As a result, the overall quality of planting seed has improved considerably in India in the past 19 years, and it is our experience that farmers appreciate and demand consistently high-quality brands of seed.

Packing

In India, crop seed is generally packed into 1-acre lots in grey or bleached cloth, laminated jute-polythene, *or* laminated cloth-polythene bags. A few companies also use polythene-lined cardboard cartons. Because seed quality deteriorates rapidly in zones of high humidity, absolute moisture proofing is essential, and several companies are trying to develop or adopt low-cost moisture-proof containers. The object is to protect the seed both from the environment and from adulteration; however, this objective is only being partially achieved at present.

Warehousing

Seed for planting requires different handling from seed for consumption. It must not only remain insect-, disease-, and moisture-free but also remain viable until planting time, a period that may range from 8 months to 20 months if seed is to be carried over. Thus storagefacilities should be excellent.

The National Seeds Project has provided funds for this purpose and the Central Warehousing Corporation, in cooperation with the National Seeds Corporation, is supposed to build these facilities to start with. However, although there is a growing awareness of the importance of good storage, facilities especially created for storage of different classes of seeds are extremely limited and much is yet to be achieved in this direction.

Seed Marketing

Marketing is a vital link in the commercialization of planting seed. Seed not marketed in time for planting cannot be marketed until the following year.

An organized marketing program must create the demand for quality seed and at the same time establish efficient channels for meeting this demand. More and more seed companies are finding that demonstrations are an effective means of popularizing new varieties or hybrids. These demonstrations are followed by field days, which are widely publicized in the farming community and generally well attended by farmers. Other promotional avenues include films, television, radio, cinema, magazines, periodicals, and newspapers.

Supply Channels

The most effective method of seed distribution is through dealers; these may be farmers, cooperatives, or dealers in other agricultural products. Seed must be easily available to the farmer well in advance of planting time. This involves creating a network of distributors at village, panchayat samiti, taluk, and district levels. Although this may present some difficulties initially, our experience is that as the volume of sales increases, more and more people become interested in dealing in commercially produced seed. We have also observed that brands that provide consistently high quality and service quickly become popular.

Pricing Policies

For the successful comercialization of planting seed, clear-cut governmental policies on pricing and related aspects are necessary. The main reason why the seed industry in pulses and oilseeds has not developed is the lack of clear policies. We find that wherever hidden or indirect subsidies are provided by the government, commercial channels find it difficult to handle such seed. Facilities are often misused, and seed is diverted for purposes other than planting —food, oil extraction, etc. Moreover, such subsidies do not necessarily popularize the seed. The most convincing reason for the farmer to use quality seed would be high profits. To this end, farmers certainly need support in the form of easy access to credit, ready availability of other agricultural inputs, and efficient marketing facilities for their harvest.

Conclusion

Although the seed industry in India is barely 20 years old, it has made tremendous strides. It handles over 10 000 tonnes hybrid jowar, 15 000 tonnes hybrid bajra, and also large quantities of hybrid maize, wheat, and paddy. Most remarkable is the unprecedented success of commercial cotton seed production. Despite the scepticism that attended the beginning of the Indian hybrid cotton seed industry, it is today commercially self-sustaining, producing over two million kilograms of F_1 hybrid seed by hand emasculation and hand pollination.

In terms of rupee value, I estimate that in 1980 the Indian seed industry will be making a turnover of about 1570 million rupees, mainly from seed of foodgrain crops, fiber crops, oilseed crops, forage crops, and vegetables. This is in no terms a small turnover.

Formulation of clear-cut policies and implementation of these in both letter and spirit could further acceleratethe rate of growth of the Indian seed industry. Efforts to monopolize certain classes of seed and preferential treatment to the governmental organizations have retarded the growth of the seed industry to a great extent.

In a developing economy, agencies often do not properly understand their roles and relationships. Even where programs and policies are written, their implementation and interpretation have been a great problem.

Our aim should be to have a more than adequate supply of good quality seed at a competitive price. This can only be achieved by motivating the industry by allowing it to make reasonable profit. Competition should be able to take care of the quality and price.

For any successful commercialization of planting seed, the entire process must work smoothly, in an orderly manner. Any missing link can entirely disrupt the whole system of commercial production and thus the availability of seed. Sufficient safeguards should therefore be provided. Monopolies at any level by any agencies, private or public, are undesirable and should not be allowed.

Problems of Supplying Improved Pigeonpea Seed to Farmers

B. M. Sharma*

Abstract

Pigeonpea is the second most important pulse crop in India, occupying about 2.6 million ha, with a production of 1.9 million tonnes. However, the multiplication and distribution of pigeonpea seed is fraught with problems caused by lack of: good quality seed, facilities for further seed multiplication, training and incentives for seed growers, and efficient distribution and marketing channels. Farmers' and consumers' traditional preferences also hamper the spread of new varieties. To overcome these difficulties, the Government of India started a scheme for producing adequate quantities of both breeders' and certified seed, involving the ICAR, state agricultural universities, and the state and national seed corporations. As a result, seed production has gained momentum in all states, and it is expected that in the future, demand for pigeonpea seed in India will be met in large measure.

Pigeonpea is one of the most important pulse crops of India. It is grown over an area of 2.6 million ha, producing a total of about 1.9 million metric tons (tonnes). The principal pigeonpea growing states are Maharashtra, Madhya Pradesh, Uttar Pradesh, Karnataka, Tamil Nadu, Bihar, and Andhra Pradesh, which collectively account for about 80% of the total pigeonpea area and over 83% of the total production in the country (Table 1).

The Growing Situation

In India, pigeonpea is cultivated in different crop sequences and in various crop mixtures. The late-maturing varieties are grown as sole crop in very limited areas in a few pockets of Uttar Pradesh, Madhya Pradesh, and Maharashtra. The major area is covered by the late and medium varieties, grown as intercrops and mixed crops with various *kharif* (rainy season) cereals, millets, and other cash crops.

Recently, the cultivation of early-maturing varieties of pigeonpea has become more popular, especially in the irrigated command areas in Punjab, Haryana, Rajasthan, U.P., and M.P., which are prone to frost. The area under the early cultivars of pigeonpea is rather restricted but is increasing fast (Table 2).

In these northwestern states, the early varieties of pigeonpea fit in well with wheat, which is the primary crop of the *rabi* (postrainy) season. Because these states are prone to frost, to which pigeonpea is very sensitive, farmers are increasingly giving up the cultivation of late pigeonpea varieties. Early varieties are also grown mixed with mung bean in April; the mung is harvested in June, but the pigeonpea crop continues up to the end of November.

In certain parts of India — e.g., Bihar, Gujarat, Orissa, and West Bengal — the cultivation of rabi pigeonpea is becoming popular, but the area is still quite restricted.

Because pigeonpea is grown across such a wide range of growing situations, there is an urgent need for seed of varieties specifically adapted to each situation. There is also a need for types resistant to the major pigeonpea diseases — sterility mosaic *and* wilt, which cause serious yield losses — and to the insect pests that are especially prevalent in late-maturing types. The problems of supplying enough high-quality seed to fit all situations in which pigeonpea is grown are numerous.

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Table 1. Aiaa,production,andyialdofplgeonpea1970-71to1878-79Indlfferentstates of India.

State	1970-71 Area (000 ha)	Production (000 tonnes)	Ave yield (kg/ha)	1978-79 Area (000 ha)	Production (000 tonnes)	Ave yield (kg/ha)
Andhra Pradesh	198.6	62.1	313	204.9	44.2	216
Assam	4.1	2.9	707	6.4	4.5	703
Bihar	150.3	134.6	896	88.8	57.4	646
Gujarat	86.0	40.8	474	131.5	74.4	566
Haryana	8.9	4.2	472	7.4	7.7	1040
Kerala	5.0	0.9	198	3.0	0.8	267
Karnataka	309.1	152.6	494	315.1	195.8	621
Madhya Pradesh	500.4	409.3	818	487.1	314.7	646
Maharashtra	639.6	304.5	476	675.8	399.2	591
Orissa	51.2	32.2	629	69.8	38.1	546
Punjab	3.0	1.2	400	7.7	4.0	519
Rajasthan	25.3	13.2	522	44.8	14.3	319
Tamil Nadu	62.7	23.0	367	105.6	48.6	460
Uttar Pradesh	582.4	678.5	1165	499.0	700.1	1403
West Bengal	25.8	22.3	864	12.7	8.4	661
Others	2.6	1.0	385	8.0	8.6	1075
Total	2655.0	1883.3	709	2667.6	1920.8	720

Table 2. Area under aarty-maturing cultivars of plgaonpea In India, 1979.

State	Coverage (ha)	Target for 1980 (ha)
Punjab	5 600	11000
Rajasthan	4 375	80 000
UP.	11 257	50 000
Total	21 232	141 000

Seed Supply Problems

The problems of cultivation and seed supply for pigeonpea *are* quite different from those of other pulse crops. Generally, farmers use local seed available from traditionally grown types in the area and are reluctantto pay the high cost of quality certified seed. They do not adopt the so-called improved management practices for obtaining higher yields, particularly because pigeonpea response to inputs is not comparable with that of the cereals and millets.

The major pigeonpea-growing areas in India are planted to late-maturing varieties. The multiplication program for seed has been very weak so far, and no concerted efforts were made to take up the systematic multiplication and distribution of seed for long-duration pigeonpea. Most improved varieties released from the universities and research stations remained confined to government farms or at most were adopted by a few progressive cultivators.

Recently, with the spread of short-duration pigeonpea varieties, the seed distribution program has been stepped up. However, farmers' traditional preferences in some matters remain an obstacle to the adoption of improved varieties.

Farmers' Traditional Preferences

In each area, farmers have certain preferences regarding seed coat color, seed size, etc., as these influence market prices.

Seed Color

Although the dhal after milling is always yellow, regardless of seed coat color, there has traditionally been a preference for a particular color in a particular locality. Thus Gujarat farmers prefer varieties with white seed coats.

Farmers in U.P. prefer red seed coats, and although in parts of this state a local variety known as "tuian" (dwarf), with very high yield potential, is grown in a few districts, its cultivation is not spreading because its black seed fetches a lower price in the market. These traditional preferences often pose a problem in increasing the cultivation of varieties with high production potential.

Seed Size

In general, large seed size is preferred for pigeonpea as for all pulse crops, as the larger seed fetches better prices in the market. Most of the pigeonpea crop is milled into dhal, and millers also prefer the large grain, as it is easier to dehusk and split than the smaller grain. The quality of dhal prepared from large seed is also better and tastier than.that made from small seed; the famous *phool* dhal of Kanpur, for instance, is made from large seed and fetches a higher market price than any other.

Thus, although the early-maturing varieties are becoming popular in the northwestern part of India, these have smaller seed and the quality of the dhal is considered inferior to that made from the traditional long-duration types. This factor hampers the spread of early pigeonpea types.

Cooking Quality and Taste

An important factor responsible for market preferences is the flavor and cooking quality of pigeonpea dhal. Certain local varieties have good flavor and taste, and farmers prefer these, especially for their own consumption, over other improved varieties.

Field Problems

Defective Distribution Channels

Although the distribution program for improved pigeonpea seed was started several years ago, it is not always effective. Seed is distributed through the agents of State Seed Corporations, the National Seeds Corporation, and the Department of Agriculture. Under our present setup, the seed does not reach the distribution point well enough in advance to be useful. Farmers are not kept informed about the improved seed available, its quality, growing requirements, etc. Therefore, even the seed that does reach the distribution points often *remains* undistributed.

Storage

Pulses in general, and pigeonpea in particular, are highly susceptible to stored grain pests. If proper care is not taken at the storage point, the stored seed gets damaged. Unfortunately, little care is taken to prevent this, especially in rural godowns, and no reliable pest- and moisture-proof devices *are* available for storing seed safely.

Lack of Incentives to Farmers

No incentives have been provided to farmers for the production and distribution of good quality seed. In some villages, farmers practice a system of seed exchange, but this is restricted to a very few villages.

Technical Problems of Seed Production

Breeders' Seed

Inadequate Quantity

There was no organization in the past for the production of breeders' seed for the improved and released varieties. Therefore, further multiplication channels remain blocked for want of sufficient quantities of breeders' seed.

Inferior Quality

Breeders' seed supplied for multiplication often does not even qualify as certified seed. Pigeonpea breeders' seed is sometimes of varying shades and raises questions about the genetic purity of the breeders' material. Even with prescribed isolation distances, a certain percentage of natural cross-pollination occurs in pigeonpea. This creates serious problems for agencies producing seed, as it often does not meet the standards required for certification.

Causes for Inadequacy and Inferiority of Seed

Lack of Facilities for Breeders' Seed Production

Pigeonpea breeders at the agricultural universities are supposed, in addition to their other research work, to multiply breeders' seed. However, no extra facilities are provided to them to ensure that quality seed is produced in the desired quantity.

Lack of Organizational Facilities for Multiplication of Seed

In the past it was the responsibility of the state governments to take up the further multiplication of seed at the foundation and certified stages. It has been our experience from most of the states that the targeted area for pigeonpea is not covered on government farms, mainly because the performance of the farm is judged by the total profit, and it is more profitable to produce wheat seed than pigeonpea or other pulse seed. Most states now have state seed corporations that are supposed to meet the seed requirements of the entire state; however, these also give low priority to the production of pigeonpea seed.

Nonrelease and Notification of Varieties

A prerequisite for the production of foundation and certified seed is that the variety should have been released and notified by the Government of India. In the past, a few varieties with good yield potential were identified but could not be notified for certain technical reasons. Existing seed laws prohibit the multiplication of such nonnotified varieties.

Difficulties in Certification

The seed laws require a minimum standard of physical purity in the field for certified seed. However, the pigeonpea crop often lacks this standard of purity and the seed is thus rejected by the certifying agencies.

Lack of Facilities for Contract Farmers

Because the state seed corporations often lack enough land to produce seed for the whole state, they employ contract farmers to do so. Such contract farming is fraught with problems:

LACK OF TRAINING. The majority of the contract farmers do not possess the necessary technical skill or training to produce quality seed for certification. The state corporations should work out a system of training in cooperation with the state agricultural universities.

LACK OF INCENTIVES. NO incentives are given to farmers who opt for producing certified seed. This discourages them from taking up seed multiplication.

DIFFICULTIES OF SEED PROCESSING. A contract farmer who produces seed for an agency is required to deliver that seed to the processing plant, which may be as much as 400 to 500 km away, at his own cost. He is then paid according to the specified rate for the quantity of processed seed; rejected seed fetches him no price at all.

PRICE FLUCTUATIONS. Because of widely fluctuating market prices of pulses, a contract farmer may stand to gain more by selling his produce as food than as seed. Thus seed farmers often break their contracts and sell the seed in the market.

Efforts to Improve Seed Production

The Government of India has launched a program to improve the production and distribution of seed for all pulse crops, including pigeonpea. Tables 3 and 4 show the production of breeders' and certified seed under this program.

Breeders' Seed

Under the program, breeders' seed is multiplied with the help of the agricultural universities, under the supervision of the concerned breeders. Appropriate targets are set for each university and the universities are paid Rs 3000/tonne of seed produced, to meet the cost of production.

At the central qovernment level, the seed is

Table 3. Production of pigeonpea seed in India, 1977-1980, and targets for 1981.

State	1977-78 prod	1978-79 prod	1979-80 prod	1980-81 target	Cultivar
Andhra Pradesh			2 690	12 000	HY-2
			1 890	6 500	PDM-1
				800	HY-4
			560		ST-1
Gujarat			1000		T 15-15
			1000		Pusa Ageti
Gujarat State Seed Corporation	130	20	1920	11000	T 15-15
			150		HY- 3-C
Haryana	1275	2 000	3 570	6 000	UPAS-120
Haryana State Seed Corporation		2 000	6 000		UPAS-120
		1000	1000		Prabhat
Karnataka State Seed Corporation			2 900	80 ha	PT-221
				30 ha	HY 3-C
Maharashtra			16 780		
Maharashtra State Seed Corporation				3 500	BDN-1,T-21, No. 148
Orissa				1 680	T-21
Rajasthan State Seed Corporation			8 000	150 ha	UPAS-120
				35 ha	T-21
Tamil Nadu	12 590	15 020	13 500		SA-1, CO-2, CO-3
Uttar Pradesh			20 000		T-21
U.P. State Seed Corporation	2 400	470	7 000		T-21
NSC		5 070	8110	39 000	T-21

a. Targets in kilograms, except where area is indicated (ha).

Table 4. Breeders' seed production program 1979-80 and 1980-81.

State	Cultivar	1979-80 (kg)	1980-81 (kg)
Bihar	Bahar	150	200
	Basant	25	100
	BR-65	70	100
	Laxmi	17	80
	BR-183	25	60
	7-S	-	60
Gujarat	T-15-15	800	500
	Pusa Ageti	550	100
Haryana	UPAS-120	2407	2500
	Prabhat	557	1500
		2964	4000
Karnataka	HY-3C, HY-3A, TT-7, C-28, PT-221,TS-136-1, BDNI&GS-1	2550	2445
Madhya Pradesh	T-21	450	
Maharashtra	N-290-21	200	24
Prabhani	No-148	100	24
	T-21		08
	C-11	30	150
Akola	No. 148	20	150
	T-21	08	40
	Pusa Ageti	20	75
Rajasthan	UPAS-120	900	3540
	T-21		1390
Tamil Nadu	CO-2	100	
	CO-3	50	

produced with the help of the Indian Council of Agricultural Research in agricultural universities and supplied to the National Seeds Corporation or to needy states and organizations.

Certified Seed

Good quality seed is always costlier, as it is handled by a number of agencies; the overhead charges are high, raising the price of seed by almost 80%. In order to make available pigeonpea seed at reasonable rates, the price is reduced to farmers by Rs 150/100 kg. Care is also taken to keep the seed price to producing contract farmers somewhat higher than the price of commercial grain in the market.

Truthfully Labelled Seed

To encourage truth in labelling, a subsidy of Rs 1007100kg was instituted to cover the cost of transportation and grading. This assistance is being gradually reduced as production of certified seed has increased.

Discussion—Session 8

C. B. Singh:

What should be the working isolation distance for breeders' seed production? Should it differ from variety to variety, depending upon the extent of outcrossing?

S. C. Gupta:

Experimental proof for this is not yet available, but we have an experiment under way at ICRISAT Center to determine the isolation distance required for seed production. In general, with currently available cultivars, I do not think that the isolation distance will vary from one variety to another.

Lal:

The reasons for high coefficients of variance for inbred lines developed from cultivars T-21 and Pusa Ageti are not known. Could you *comment on* this?

S. C. Gupta:

The coefficients of variance presented in the tables are not for specific locations. These have been calculated across locations to get a rough idea of comparative stability against source cultivar T-21. The CVs obtained for the T-21 pure lines are comparatively lower than for the check, T-21.

Green:

That is a very crude estimate of stability of performance.

Faris:

Considering the variability among lines shown in the graphs by Dr. Gupta, can one expect to maintain the genetic variability in the original variety without genetic drift when lines are reduced to only 20?

Green:

We practiced selection in these lines. When the selfing was initially started in the varieties, there was ample room for selection, and our aim was to select lines close to the norms of the source cultivar. We found it difficult to select progenies that resemble the source cultivar. For example, when we selected 100 random plants among the open-pollinated population of T-21 and planted them as single-plant progenies, we had difficulty in selecting progenies that were exactly similar to the source cultivar.

D. Sharma:

We started with 100 plants and we did not finally reduce our maintenance to 20 lines. We selected 20 lines based on their uniformity and closeness to the source cultivar, five to ten plants in each of these 20 lines were then selfed and used for initiating the next cycle of selection. So the effective population level in each cycle of inbreeding was maintained at 100 to 200 lines. In this process, we ended up with some lines superior in yield to the source cultivars. Finally, we have retained only the two top-yielding lines for each of the cultivars and these are being maintained at a population level of 100 to 200 plants.

Green:

What is notification of a variety? As far as I know, cvs Sharda and Mukta are obsolete by now.

Balaraman:

Notification is a statutory requirement under the Seeds Act, 1966. If a variety is not "notified" it will not come under the purview of the Seeds Act and so it cannot be certified. If the Government of India feels that the quality of seed of a crop variety must be regulated, then it notifies that variety. The provisions of the seed act which is a quality control act, then become immediately applicable to it.

von Oppen:

I should like to ask Mr. Balaraman the details on the cost of pigeonpea seed production.

While the procurement rate is only Rs 420/100 kg, the sale price is more than Rs 700/100 kg. How is this increase in rate explained?

Balaraman:

To the procurement price of Rs 420, we will have to add, per 100 kg, cleaning charges (Rs. 15), purchase tax (Rs. 17), treatment and packing charges (Rs. 43), transportation charges (Rs. 35), interest (Rs. 30), storage charges (Rs. 5), dealer's commission (Rs. 70), and overhead charges (Rs. 100). These items bring the total sale price of 100 kg of pigeonpea seed to Rs. 735.

M. C. Saxena:

The cost estimates for seed production given by Mr. Balaraman may be commented upon by Mr. Barwale.

Barwale:

The cost estimates given by Mr. Balaraman are on the lower side.

M. C. Saxena:

There is a need for resolving the contradictory suggestions made by the two seed-producing agencies about subsidy for seed.

Barwale:

There is no need for any subsidy. From my own experience of 19 years, I say that the farmer has never grudged the cost of seed when he can make a profit. So we should not worry unduly about the cost of the seed, particularly in a crop such as pigeonpea, where the seeding rate is only 4 kg/acre and the additional cost of using improved seed may be about 2 to $2^1/_2$% of the total cultivation costs.

Balaraman:

If pulse production is to be increased and farmers encouraged to use quality seed, subsidy is a must, at least in the initial stages. Without subsidy, seed prices will be very high. With many other crops, subsidy has helped increasethe use of quality seed. In jute, where seeding rate is low, a subsidy scheme has considerably increased use of certified seed.

Misra:

Seed-producing agencies such as the National Seeds Corporation or private firms should have their own network of sales centers at the panchayat or block level so that farmers can get seed of a particular crop variety well in time to grow improved types over a maximum area.

Barwale:

I wholly agree with the suggestion that there should be sales centers but do not agree that we should have our own dealers; instead, the centers could be managed by independent dealers.

Kurien:

Dr. B. M. Sharma pointed out farmers' and millers' preferences for particular seed size and color. In the eastern region of India, a very light-colored dhal is preferred; on the contrary, in southern India, a very deep colour is preferred. Thus dhal in the south is often colored with a water-soluble dye. In U.P., pigeonpea seed is graded, the larger seed being used for making "phool" dhal and the smaller for second-quality dhal.

Session 9

Utilization

Chairman: S. G. Srikantia

Rapporteurs: Umaid Singh
C. L. L. Gowda

Advances in Milling Technology of Pigeonpea

P. P. Kurien*

Abstract

Pigeonpea is consumed in the Indian subcontinent mainly in the form of dhal, or dehusked splits. Conversion of this grain is an age-old practice, which originated in the home, later developed into a village industry, and has now grown into a large-scale organized industry. Today thereare morethan 10 000 dhal mills of varying capacities in India, located mostly in pig eonpea-growing areas. Processing losses, however, are still considerable, and increased agricultural production can make little impact until these losses are reduced. The Central Food Technological Research Institute in Mysore has developed improved technology for milling pigeonpea, which allows round-the-lock operation, is independent of weather conditions, and gives a higher recovery of dhal (80-84%) at lower cost. This improved process could give an 8 to 10% increase in the availability of pigeonpea dhal in the country.

Pigeonpea is one of the major food legumes grown and consumed extensively in the Indian subcontinent (Anonymous 1979). About 90% of the world production comes from this region, where it forms an important adjunct to vegetarian diets. It is consumed mostly in the form of dhal or dehusked splits (Government of India 1958), as denuding reduces the fiber content and improves the appearance, texture, cooking quality, palatability, and digestibility of the grain.

Denuding is an age-old practice, which probably originated in the kitchen, later developed through village-level operations into a large-scale organized industry (Kurien and Parpia 1968). Today there are about 10 000 milling units of varying capacities for processing the annual Indian pigeonpea production of about 2 million tonnes. Dhal milling is next only to rice and wheat milling in importance and the industry employs several hundred thousand people.

Traditional Methods of Milling Pigeonpea

The operations involved in the dehulling of pigeonpea can broadly be classified into two steps: (1) loosening the seed coat by wet or dry methods, and (2) removing the seed coat and splitting the cotyledons. The first step of loosening the husk remains largely traditional, the operations being carried out on a larger scale than in home-scale techniques. With the advent of the machine age, a certain amount of mechanization has been achieved in the second step.

The premilling treatments for loosening the hulls consist of one or more of the following operations:

1. Prolonged sun-drying until the seed coat is loosened.
2. Application of small quantities of oil and/or water, followed by several days of sun-drying.
3. Soaking in water for several hours, followed by coating with red earth slurry and sun-drying for several hours.
4. A combination of these techniques.

These operations as practiced at present are laborious, time-consuming, and completely dependent on climatic conditions, requiring good sunshine and favorable weather for processing.

The second step of removal of husk and splitting is done using hand- or power-operated machines. Pounding in a mortar and pestle was

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the earliest technique used in homes. Later, hand-operated shellers known as *chakki* came into use; these perform both the dehusking and the splitting. The husk is removed by winnowing. The large mills use power-operated disc shellers, emery-coated roller machines, polishers, buffing machines, oil and water-mixing worms, aspiration boxes (to remove husk and powder), and automated sieves to grade grains or separate and grade dhal.

The flowchart of the typical dry method of processing is given in Figure 1. Table 1 (CFTRI 1971) shows yield of dhal and other fractions from different processing methods.

Traditional millers are aware that the milling characteristics of pigeonpea are influenced by variety and agroclimatic factors, but this phenomenon is not fully understood. The husk is attached to the cotyledons by a layer of gums and lignin (Kurien 1971b). The adherence of the husk to the cotyledons depends on the tackiness of these gums, which in turn depends on the amount, chemical nature, and extent of hydration.

Various premilling treatments employed in traditional processes are aimed at loosening the husk (Kurien and Parpia 1968). In the wet process, when the grains are soaked in water, the soluble gums leach out into the soak water. The grains swell, and on drying the cotyledons shrink more than the husk, resulting in a "bubbled" husk. The cotyledons also cave in at the surface of fusion, and abrasion pressure exerted by shellers separates the husk and splits the cotyledons (Kurien and Parpia 1968). In the dry methods, a "pitting" operation is done in a roller mill to crack the seed coat and facilitate the penetration of oil into the gum layer. Under the mild heat of the sun, the oil spreads over the gum layer and reduces its tackiness. As the mechanism of adherence of the husk to the cotyledons is not fully known, the millers use a complex process in a sequence and time schedule evolved through the years to condition the grain for easy dehusking.

Premilling treatments and the milling machinery used vary considerably. Bold grains, kharif-crop grains, and grains stored for a long time (presumably due to drying) are generally considered easier to dehull than small grains, rabi-crop, or freshly harvested grains. Millers have preferences for crops grown in certain tracts as they are easy to mill. Such grains are believed to give a higher yield and better quality dhal. For processing difficult varieties, millers resort to addition of more oil, longer periods of sun-drying, treatments with alkaline solutions,

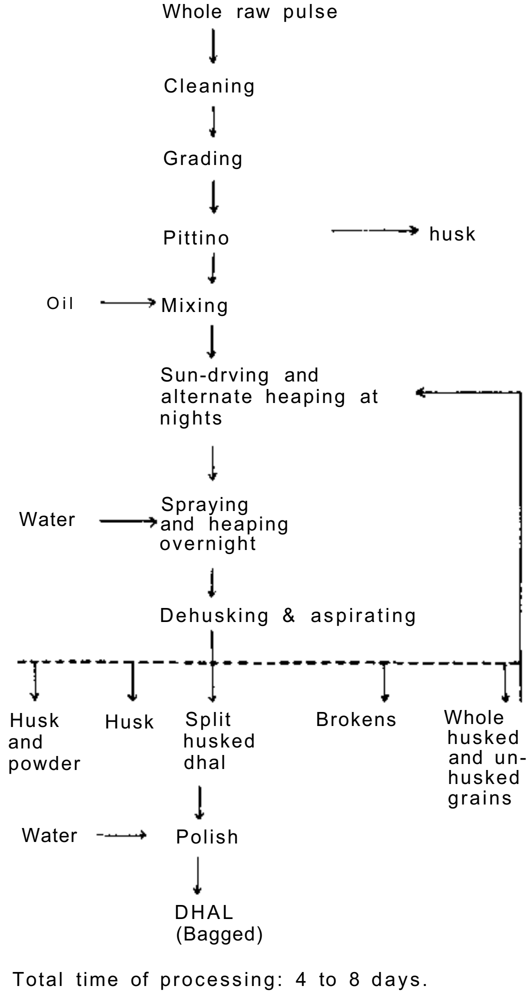

Figure 1. A typical flow diagram of traditional milling of arhar (Source: Kurien and Parpia 1968).

Table 1. Yield (%) of dhal and by-products from pigeonpea by various traditional techniques.

	Dhal	Brokens	Powder	Husk
Dry method				
Big grains	75	5	11	8
Small grains	68	8	14	9
Wet method	75	7	3	14

and more passes through the milling machines. The effectiveness of the premilling treatments to loosen the husk is well reflected in the efficiency of milling machines (Kurien and Parpia 1968).

The two major dehusking machines extensively used are the disc shelter and the roller machine (Kurien 1971a). The disc sheller, generally used for wet processing, works on the principle of attrition and is used to remove the husk and split the cotyledons simultaneously. However, there is no proper understanding of the mechanism of its functioning, and excessive breakage in this machine is common, especially when the grains are not size-graded. Revolutions of the disc, roughness of contact surfaces and their parallelism, the effective distance and duration of grain movement between the discs as it takes its parabolic path, etc., are important factors to be considered in the construction of efficient shellers (Kurien 1977).

The roller machine is commonly used in dry methods of processing and works on the principle of abrasion. Though efficient for dehusking if properly constructed, it is used by millers for both dehusking and splitting; when used improperly, this machine causes scouring and powder losses. Various factors such as abrasion force as determined by surface speed, abrasion pressure as determined by feed and discharge of grains, roughness of the rollers fordehusking or polishing, time of stay of grains in the abrasion chamber, clearance between the roller and sieve, etc., are to be considered in the construction of this machine for efficient performance. Often, because of inadequate premilling treatments, this machine gives only 25 to 50% dehusking in the first pass. In the second and subsequent passes to remove the husk, the pearled grains get scoured on the periphery, causing appreciable scouring losses (Table 1). As the proteins are concentrated in the peripheral layers of the grain, there is a disproportionately high loss of proteins in this powder fraction.

Influence of moisture in the dry methods of milling appears to be fairly well understood. Moisture is recognized to have opposite effects on dehusking and splitting (Kurien and Parpia 1968). Low moisture is needed for dehusking, while water is added for splitting cotyledons. In certain places, dehusking and splitting are done separately to get higher yields of high quality dhal with sharp edges. Where dehusking and splitting are simultaneously carried out, the edges of the split cotyledons are rounded off, causing powdering and adversely affecting the commercial value of the dhal (Kurien 1971b; Siegel and Fawcet 1976).

Improved Methods of Milling Pigeonpea

Traditional technologies and machines have several limitations and difficulties; therefore, attempts have been made either to improve upon the traditional methods and machines or to develop new ones. Although certain machines developed in other countries for beneficiation of cereals and millets have been used for dehulling grain legumes, recovery of dehulled grains is not as much as in traditional methods (CFTRI 1977). Moreover the dehulling of grain legumes, particularly pigeonpea, can be efficiently and economically done in the two general steps of premilling treatments to loosen husk and dehulling followed by splitting. A suitable technology and machinery have been developed at Central Food Technological Research Institute, Mysore, India, for dehulling pigeonpea and other grain legumes.

The husk of pigeonpea can be loosened and made brittle and pulverizable if treated under appropriate temperature conditions and dried to a critical moisture level. The temperature conditions and critical moisture level vary from one cultivar to another, but satisfactory milling characteristics can be imparted to the most difficult-to-mill ones if they are pretreated under proper conditions. The grain can be hardened, and the extent of splitting reduced considerably by reducing the moisture content and, thereby, scouring losses. These findings form the basis of the improved technology developed at CFTRI.

Milling Characteristics of Pigeonpea

Several factors influence the milling characteristics of pigeonpea and these must be considered in developing suitable premilling treatments to loosen the husk (Kurien 1977): the content of husk and its hardness; the amount, chemical nature, and hydration level of the gums; the shape, size, and moisture content of

Table 2. Milling characteristics of 19 varieties of pigeonpea.

Variety	1000-grain wt (g)	Husk (%)	Cotyledon (%)	Degree of dehusking (%)	Apparent yield (%)			True yield (%)
					Splits	Pearls	Total	
Commercial UP. variety	70.9	12.5	86.4	67.1	35.9	44.3	80.2	76.8
BS-1	76.8	14.5	84.2	88.6	50.3	27.6	77.9	76.6
T-21	79.6	14.8	83.8	91.4	33.1	46.1	79.2	78.2
S-8	84.2	14.1	85.0	87.9	48.6	29.5	78.1	76.8
S-5	85.2	15.5	83.4	75.2	44.4	35.0	79.4	76.3
ICP-7221	90.9	12.3	86.7	81.3	25.8	54.9	80.7	78.8
ICP-7118	95.6	14.0	85.0	94.2	43.6	35.1	78.7	78.1
ICP-1	97.3	13.9	85.3	70.3	44.5	33.8	78.3	75.0
G. local	97.9	13.2	85.8	84.6	66.6	7.1	73.7	72.3
ICP-7120	98.9	14.1	85.1	82.3	20.5	58.9	79.4	77.4
HY-1	103.1	12.7	86.3	72.1	67.8	11.6	79.4	73.2
ICP-7182	104.7	13.5	85.5	90.8	55.5	23.1	78.6	77.6
HY-4	107.2	14.1	85.0	85.8	36.6	41.9	78.5	76.9
Hyd-2	119.9	12.7	86.6	85.0	72.8	2.3	75.1	73.8
HY-2	132.9	11.6	87.5	84.1	69.0	10.9	79.9	78.4
ICP-7119	177.3	13.0	85.9	85.2	71.1	7.0	78.1	76.6
HY-3C	188.1	11.0	88.2	85.0	75.6	3.6	79.2	77.9
HY-3A	190.9	10.5	88.9	87.6	75.0	4.8	79.8	78.8
S-141-31	191.6	14.8	84.0	100.0	20.8	61.2	82.0	82.0

Source: Ramakrishnaiah and Kurlen, unpublished.

grains, hardness or softness, etc. The seed coat must be properly conditioned, for easy removal in the machine with a minimum loss of kernel.

In a study of physical properties and milling characteristics of several varieties of pigeonpea, scientific explanations of some of the properties exhibited by this grain during dehusking have been found. Several investigations involving 18 pure strains and one commercial variety of pigeonpea are summarized in Table 2 (Ramakrishnaiah and Kurien, unpublished).[1]

Husk and Cotyledon Content

The husk content of pigeonpea varieties studied varied from 10.5% to 15.5% (Table 2). As the germ content is low (0.6-1.4%), the cotyledon content is high in varieties with low husk content and vice versa. However, there is no definite correlation between the seed size and husk content of a variety. Big bold grains have both high and low husk contents; e.g., S-141-31 (148%) and HY-3A (10.5%). However, smaller grains generally have a higher content of husk.

Degree of Dehusking

The extent to which the husk is removed when pigeonpeas are heat-conditioned under uniform temperature and moisture conditions (to loosen husk) and then denuded in an abrasion type machine, also under uniform conditions, is given in Table 2. Some varieties can be easily dehulled, while others cannot; however, the size of the grain and the husk content do not appear to influence the degree of dehusking. When processed under uniform conditions of moisture (6.5-7.0%), the husk of the variety S-141-31 was well loosened so as to be removed completely while other varieties reached different levels of loosening, as indicated by varying degrees of dehusking. This

1. N. Ramakrishnaiah and P. P. Kurien, unpublished, Varietal variations in milling characteristics of *tur* pulse.

also indicates the possibility of the husk being adequately loosened at a different (low) moisture level by different (drastic) heat treatments.

Effect of Moisture on Degree of Dehusking

Figure 2 shows the effect of moisture on the degree of dehusking in three selected varieties of pigeonpea (S-141-31, T-21, and a commercial U.P. variety), when they are heated and dried at 55 to 60°C to different moisture levels and milled under uniform conditions (Ramakrishnaiah and Kurien, unpublished). As the moisture level goes down, the degree of dehusking increases until it reaches a maximum. The maximum degree of dehusking reached as a result of this drying treatment varies from one cultivar to another; S-141-31 gave complete dehusking at 6.0 to 6.5% moisture level and the commercial variety reached a maximum of 60% at about 8.0% moisture. Further reduction in moisture does not increase the degree of dehusking. These moisture levels may be called "critical," as the grain shows the maximum dehusking at or below that moisture level.

Effect of Temperature on Degree of Dehusking

Figure 3 shows the effect of temperature on the degree of dehusking (Ramakrishnaiah and Kurien,unpublished). For comparison, the grains are heated at different temperatures until the moisture content reaches a constant level of 7.5 to 8.0%. A critical moisture level can be reached at low or high temperatures. A difficult-to-mill pigeonpea cultivar, like the commercial U.P. one, can be more easily dehusked if heated at high temperatures; cvs T-21 and S 141-31 also show improved dehusking under high temperatures; S-141-31 shows complete dehusking even at a higher moisture level than its normal critical level (see Figure 3). However, temperature and duration of heating must be carefully determined, as prolonged heating at high temperatures will adversely affect the taste and flavor of dhal.

Yield of Dhal

Apparent yield, extent of splitting, and trueyield (completely dehusked grains) aregiven in Table 2. The yield usually depends on the cotyledon

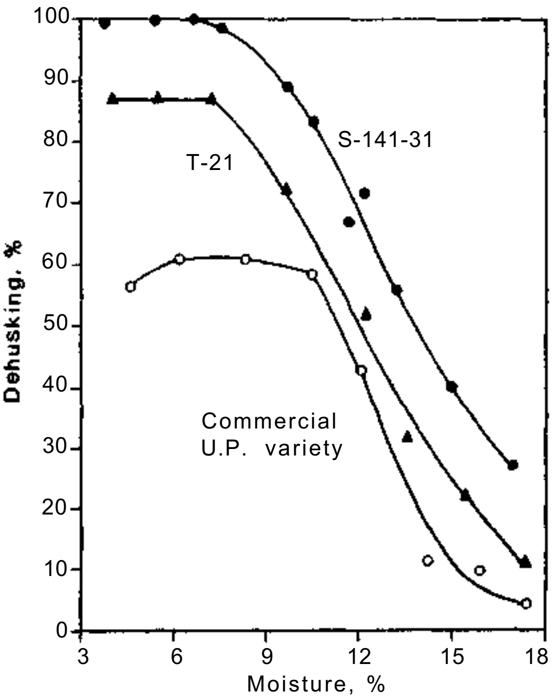

Figure 2. Influence of moisture on degree of dehusking.

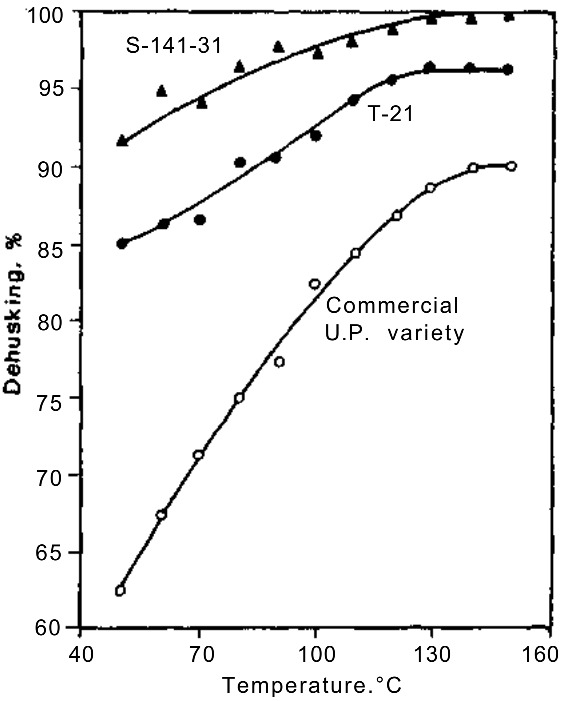

Figure 3. Influence of temperature on degree of dehusking.

content of the varieties, although the extent of scouring in the machine is a major influencing factor. Moisture reduces the hardness of the grain and helps to split the cotyledons when a larger area of the grain, particularly the edges, are exposed to the scouring action of the roller. In some varieties like HY-2 and G. local, the splitting is very high (726% and 66.6%) and gives a lower yield of dhal than varieties like S 141-31 or ICP-7120, where the splitting is low (20.8% and 20.5%) and hence the yields are higher. However, a variety that has low husk content and split to the extent of 75.0 to 75.6% gives a higher yield and less powdering, because the grains are hard enough to resist scouring at that moisture level — HY-3C or HY-3A, for example.

Improved Commercial Technology

The CFTRI technique of dehulling pigeonpea consists of two stages. The first step of loosening the husk is an incipient toasting of the grain in a current of heated air, followed by tempering when the seed coat becomes loosened and brittle (Kurien 1971b). The second step is dehusking the grain in an abrasion-type roller machine and splitting under appropriate conditions.

Loosening of seed coat involves conditioning the whole grain with hot air at 120 to 180°C in specially designed conditioning chambers where the grain attains 70 to 95°C, depending on the variety (Kurien 1977). For effective heat transfer, a counter current through-flow technique is adopted, using a conditioning chamber where hot air enters the grain mass and moves upwards, while the fluidized grain mass moves down by gravity. The grains after equilibration of the temperature in the lower reaches of the chamber are stored in perforated tempering bins with aeration vents for slow cooling and evaporation of moisture until the grain reaches its critical moisture level, after which husk can be easily removed.

The removal of the husk is done in an improved abrasion-type pulse dehusking machine (Kurien and Ramesh 1969). Feed and discharge rates, abrasion pressure and force, clearance between the cage and roller, etc., can be adjusted to suit the grain and to get a high level of dehusking (usually 95 to 99%) in a single pass. Most of the husk gets pulverized and falls off through the wiremesh sieve. Since the grains become hard due to loss of moisture, the peripheral scouring is negligible. Some of the grains (depending on the variety) are split but dehusking is almost complete.

After the husk and powder have been aspirated, the splits are separated by sieving and polished with water to restore the moisture lost during conditioning. A small quantity (0.1-0.2%) of oil may be added at this stage to impart a glossy appearance to the dhal.

The unsplit pearled grains are mixed, when still warm, with 4 to 6% water (about 1% more than that lost during conditioning) and equilibrated for about an hour, when lumps are formed due to hydration of gum. After the lumps are broken up, the grains are aerated under specific conditions standardized for the purpose, when the binding between the cotyledons gets loosened and they can be split in an impact-type splitting machine. Thedhal *formed* is separated. The unsplit pigeonpeas (usually 5-15% depending on variety) are recycled for dehusking and splitting.

In an alternative dry technique *of* splitting (Matenhalia and Kurien, unpublished), the unsplit grains are heated to 55 to 60°C and then aerated with moist air at 65 to 70% RH for 4 hours, to loosen the binding between the cotyledons, which are then split in an impact-type machine.

The flow diagram of the technique is given in Figure 4. Yields of dhal obtained from pigeonpea grown in five different agroclimatic tracts are given in Table 3 and compared with

Table 3. Yield of dhal from commercial varlaties of plgeonpea by CFTRI and trad ltional methods.

Variety	Average yield (%) Traditional method	CFTRI method
Lathur white	75	84
Hyderabad red-white mix	72	81
Bihar red-white mix	70	81
U.P. grey	68	80
Mysore red	64	79

Source: Kurien at al. 1972.

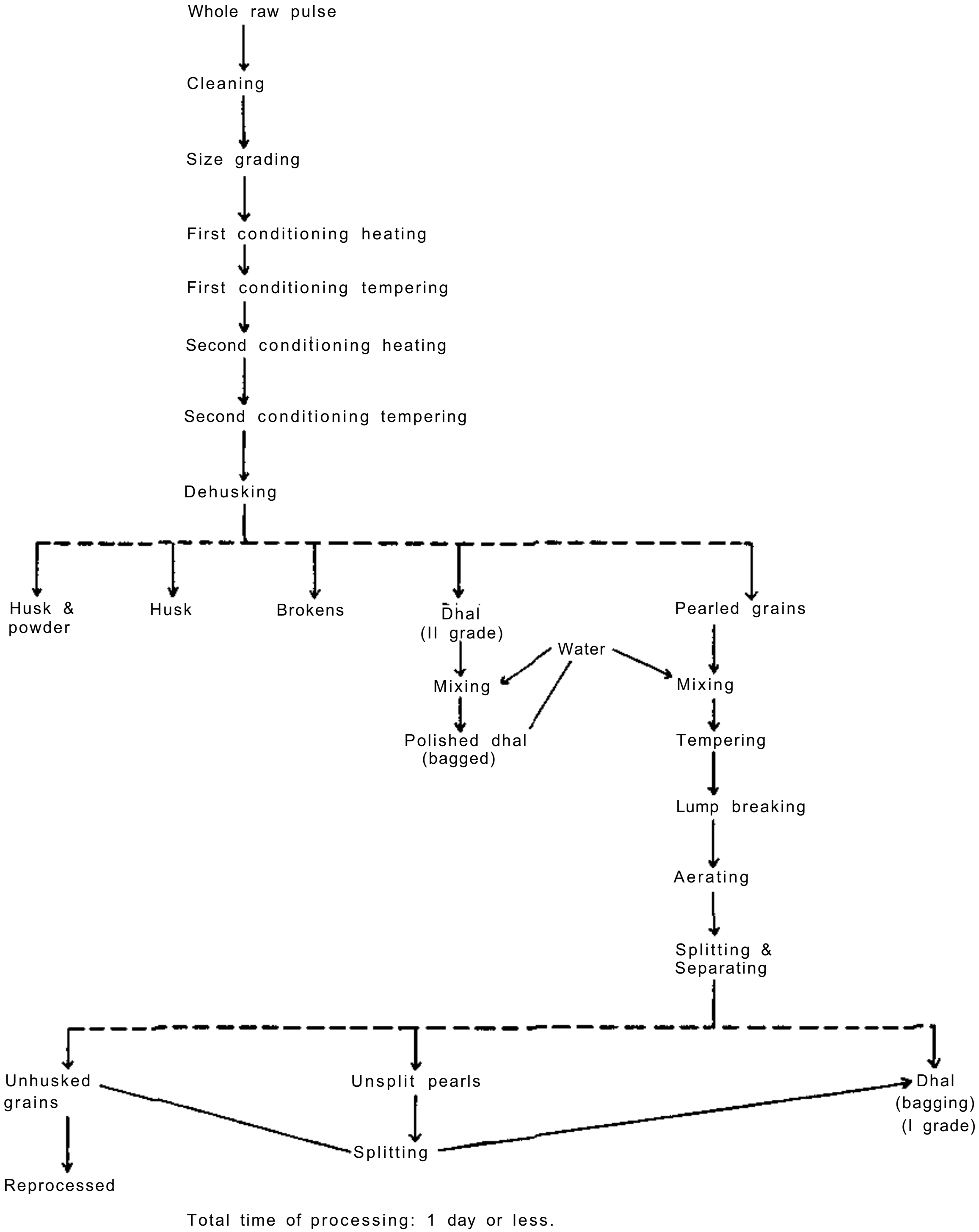

Figure 4. Flowchart of improved dhal-milling process, CFTRI.

the average yield of dhal obtained by traditional techniques (Kurien et al. 1972). This process has now been scaled up to commercial levels and has been adopted in several centers. As the process gives a higher yield of better quality dhal and is independent of climatic conditions, commercial mills based on this technology work round the clock, throughout the year. The cost and time of processing are reduced considerably (Table 4).

Table 4. Comparison between traditional and CFTRI technology for dhal milling.

	Traditional	Improved CFTRI
Weather dependence	Needs good sunshine	Independent of weather
Processing time	4-8 days	Less than a day
Quality control	Fair	Good
Energy requirement	60 KWH/tonne	85 KWH/tonne
Equipment utilization	30-40%	90%
Yield of dhal	68 to 75%	80 to 82%
Cost of processing	Rs. 274/tonne	Rs. 175/tonne

Conclusion

Although processes and machines have been developed to solve some of the major problems of the dhal milling industry, further work is necessary to (1) improve the milling efficiency of the dehusking machines, (2) develop suitable techniques to separate husked from unhusked grains so as to avoid the splitting step and save the germ portion, (3) study the nature of gums and other carbohydrate constituents and assess their influence on the milling quality, (4) develop suitable techniques to recover the edible portion from the by-products, and (5) screen the newly evolved cultivars of pigeonpea for their milling characteristics.

Increases in agricultural production of pigeonpea will make little impact without simultaneous adoption of improved processing technologies to minimize processing wastages. Genetic improvements for superior milling characteristics, seed size and shape, development of efficient processing methods and machinery, etc., are some of the urgent measures called for to combat the shortage of pigeonpeas.

References

ANONYMOUS. 1979. Agricultural situation in India, 1979. 34 (39).

CFTRI (Central Food Technological Research Institute). 1971. Pulses in India: production, agriculture, processing and consumption. Mysore, India: CFTRI.

CFTRI (Central Food Technological Research Institute). 1977. A brief overview of the grain legume situation (production, processing, utilization and storage). *In* Proceedings, FAO Expert Consultation on Grain Legume Processing. Rome, Italy, AGS/GLP/77/2.

GOVERNMENT OF INDIA. 1958. Marketing of pulses in India. Agricultural Marketing Series, Nagpur, India.

KURIEN.P. P. 1971. Stemming protein shortage. World Trade 3: 57.

KURIEN, P. P. 1971. Traditional and improved methods of milling pulses. *In* Proceedings, Conference on Milling of Dhal. CFTRI, Mysore, India.

KURIEN, P. P. 1977. Grain legume milling technology. *In* Proceedings, FAO Expert Consultation on Grain Legume Processing. Rome, Italy. AGS/GLP/77/11.

KURIEN, P. P., and PARPIA, H. A. B. 1968. Pulse milling in India. I. Processing and milling of tur (arhar). Journal of Food Science and Technology 5: 203.

KURIEN, P. P., and RAMESH, A. 1969. Improved pulse dehusking machine. Indian patent No. 122024. Patent Office, Government of India, Calcutta.

KURIEN, P. P., DESIKACHAR, H. S. R., and PARPIA, H. A. B. 1972. Processing and utilization of grain legumes in India. Ministry of Agriculture and Forestry, Tropical Agriculture Research Series No. 6, Tokyo, Japan.

MORTON, J.F. 1976.Pigeonpea(*Cajanus cajan):* ahigh protein tropical bush legume. Horticulture Science 11: 11-19.

SIEGEL, A., and FAWCET, B. 1976. Food legume processing and utilization. International Development Research Centre Publication TS1, Ottawa, Canada.

Commercial Dhal Milling in India

K. G. Matanhelia*

Abstract

Pigeonpea in India is traditionally consumed in the form of split, dehusked dhal. Various processes are used to condition the whole seed for ease of processing. This paper describes a new processing system that offers several advantages over traditional methods, including higher dhal recovery, a better product, and lower operating costs. Measures to encourage its adoption and to educate the consumer to use dehusked whole pigeonpea in place of the split dhal are also suggested.

For the best utilization of pigeonpea, we must consider the availability of this commodity, its nutritional value, and the consumer's habits and preferences. In India now, pigeonpea is becoming increasingly in short supply. While the population is constantly on the increase, there has neither been a breakthrough in agricultural technology to obtain higheryields nor an increase in the areas under pigeonpea cultivation. With the introduction of high-yielding varieties and better methods in the cultivation of wheat, rice, and sugarcane, the entire economics of agriculture in India has changed. The cultivator is now less interested in growing pulses and considers them only as a secondary crop. Two or three decades ago, pigeonpea could fetch no more than 60 to 70% of the price of wheat; in recent years it has begun selling for more than double the price of wheat. The price ratio has thus altered by three or four times; even so, it does not seem to hold enough attraction for the cultivator. Our agricultural institutes should therefore analyzethesituation and find ways of solving this problem.

One of the hurdles, I think, is the long duration of the crop, which keeps the field occupied for 8 to 10 months, depriving the farmer of the chance to grow two or three crops in the same field and also remaining exposed to natural hazards such as floods and frosts. Work on short-duration varieties is lacking both in quality of produce and in the promotional backing needed to make these varieties popular with the grower.

Nutritional Value of Pigeonpea

Pigeonpea, like other pulses, is high in protein. When milk and eggs are becoming more and more out of reach of the common man, we should accept it as our responsibility to provide the maximum possible amounts of pulses in general, and pigeonpea in particular, for human consumption. We cannot afford wastage, even if the by-products can be used as cattle feed.

To consider any prospect of improvement, we must take into account the existing practices. We have to look at food habits and food values in regard to the commodity we are trying to improve.

As is well known by now, pigeonpea, when consumed along with cereals, provides a delicious and nutritive balanced diet. This combination has evolved out of unknown but most elaborate research work not done in research institutes but based on experience.

Consumer Requirements

Pigeonpea is processed into dehusked split dhal and marketed to the consumers, who cook it in various ways, the most common of which is dhal curry. There is a lot of scope for improvement in processing methods and some minor adjustments are needed in consumer habits also to eliminate wastage of available quantities of pigeonpea.

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At present, the consumer's requirements (or prejudices) are that the product should

- be free of husk;
- be split in two halves with unrubbed, sharp edges, and should have natural luster and color, and, if possible, contain part of the germ as well;
- cook well, and have a good taste and flavor;
- take the minimum possible time for cooking.

These are generally the consumer's requirements, and the success of a processing unit depends on the extent to which it can meet them. There is a competition in this direction and the preference of the plant and machinery is also guided by the capacity to meet these preferences of the consumer.

A change in these preferences cannot be easily made; however, it may be possible to remove the consumer's prejudice in favor of split dhal only. He could be persuaded to purchase dehusked whole pigeonpea (*gota*), which cooks still better and also saves the germ of the seed from being screened off along with husk and powder, which ultimately goes to cattle feed. The germ constitutes about 2.5% of the grain and is rich in nutrients, even containing 6 to 8% fats. Whatever the reasons may once have been for splitting the whole seed into dhal, they no longer apply, and the consumer should be educated to accept whole pigeonpea or *gota* in place of the split dhal. This will increase pigeonpea availability by about 2 to 2.5% and will eliminate one step of the processing, saving processing costs and power by 25%.

Processing of Pigeonpea

Until the consumer begins to accept whole pigeonpea, however, the raw pulse will continue to be converted into split dhal, and the manufacturer of a plant and machinery must meet this requirement, and try to devise improved processing techniques to provide higher dhal yields. The best processing system will also provide the best quality of dhal because the husk is removed with a minimum of rubbing; thus the product will also have the best color, luster, and cooking quality.

The process of splitting pigeonpea into dhal is an age-old practice that evolved simultaneously in many parts of India, at a time when communications were not as convenient as they are today. The various systems differ in details, but the basic aim is the same: to make the dehusking easy. The people who devised these methods may not have known that the husk is attached to the cotyledon by natural gums, but they did observe that a certain treatment was necessary to make the binding ineffective. The effect of heat, oil mixing, water mixing, and even mud mixing was examined in various parts of the country. On a household level, the heating of raw pulse in hot sand to loosen the husk was very usefully practiced; this gave the best quality of dhal, with the best flavor, completely husk-free, with no powdering.

In the late 1960s, the Central Food Technological Research Institute in Mysore took up a study of the existing systems of processing in order to develop an improved system. This process uses a heating and cooling treatment for easier and more effective dehusking with almost no rubbing, thus reducing powdering losses substantially and giving higher yields and a product better in both appearance and flavor. For most cooking purposes, this dehusked whole is as good as the split dhal, and the consumer would not have had to change his food habits to use it. Unfortunately, however, no systematic campaign of advertising and consumer education was followed to "sell" the idea of using the whole seed of pigeonpea.

As long as the consumer prefers split dhal, therefore, I think that the processing unit or machine manufacturer must provide it. Unless a *processing system meets this demand, it will* not be adopted even if it can provide a better product or higher yield. In our modern process, we recommended a dry system of conditioning to loosen the husk and halves of the seed and make for easy splitting. This system eliminates water mixing and saves on manual handling of the stocks in process.

After a careful study of the previously prevailing systems and the new one, I am definitely of the opinion that the modern system of dhal milling should be adopted in India on a nationwide scale, and also in other countries where food habits demand a dehusked, split product. Depending on the pigeonpea cultivar processed, it can provide an extra yield of 5 to 8 % dhal, because dehusking can be done with no rubbing, thus reducing powdering losses. Though the percentage of extra yield varies with period of harvest, climatic conditions, periods of storage, and place of processing, the yield is always higher than with other methods.

Not only does the new system of conditioning provide extra dhal yield, but it costs less and will also save considerable quantities of edible oils. The traditional systems require that edible oils be mixed into the raw pulse in ratios ranging from 200 to 800 g/100 kg:

The new system also eliminates sun drying the pulse for 3 to 8 days. For such time as the stocks remain on the drying platform, they are exposed to damage by unexpected rains, which can cause serious losses as the commodity is highly hygroscopic.

The new system eliminates water mixing. In my experience, water mixing lowers the quality of the dhal; each time water is mixed into the material during or after processing, cooking quality deteriorates and the dhal requires longer to cook. Storage quality also deteriorates.

I was a dhal miller of the traditional type before I took up this project to develop the new system of milling. I am happy to say it is now fully capable of replacing the old system in the milling industry; we have already marketed several plants and the product is not only well accepted but even given preference.

Conclusion

In conclusion, I would like to make a few suggestions:

1. That it is necessary to convince pigeonpea processors of the advantages of the new system — higher yields at lower cost. Government support through its public sector undertakings could encourage wide acceptance of the system.
2. That to speed up the changeover, the government provide such incentives as grant of loans for capital investment, investment subsidies, and even tax reliefs for a certain declared period.
3. That simultaneously efforts be made to educate the consumer to accept the dehusked whole pigeonpea in place of the split dhal. This will make an additional 2 to 2.5% of the pulse available for human consumption. Here again, I would suggest the government give some reliefs in sales tax, etc., to cover possible losses to the processing units in the initial stages.

   That we are at a very delicate juncture of the changeover from the old system and cannot risk creating any misunderstanding among the public through premature claims or incomplete procedures. Issue of fresh licenses must therefore be done with utmost care.
5. That the research institutes and machine manufacturers continue the search for further improvements in the process.

Marketing of Pigeonpeas in India

M.von Oppen*

Abstract

India is the world's largest producer of pigeonpea, which is widely grown and consumed in almost all parts of the country. In the past two decades there has been a shift in pigeonpea production from the north to the north central states and to the south. About 35% of the quantity produced enters primary wholesale markets, while65% is retained on the farm. Producers and consumers respond to price changes. The decreasing per capita net availability of all pulses, including pigeonpea over the past 15 years explains the long-run trend of rising pigeonpea prices.

The variation of prices at which different lots of pigeonpea may be transacted on any market day reflects consumer preferences and can be explained to a large extent by variation in certain quality characteristics. This price variation across lots transacted is explained by variation in quality. A set of evident as well as cryptic quality characteristics explains about 70% of the variation in prices. The recovery rate when pigeonpea is milled into dhal, the volume increase after soaking, protein content, and color are among the variables explaining the price of pigeonpea.

Pigeonpea is widely grown and consumed in almost all parts of India; with 1.8 million metric tons (tonne), India produces 90% of the world's supply. A relatively well-integrated market network assures that pigeonpea prices are competitive across the country. The shifts in area and productivity of this crop that we observe over the past 20 years therefore reflect the effects of changes in demand and of changes in the relative position of pigeonpea when competing for land with other crops.

Both area and productivity of any particular crop *at* any point in time have to be viewed in the light of market forces continuously inducing adjustments. In the case of pulses, in India such changes have mostly occurred in the absence of large direct interventions, without any major technological advances, but simply in response to changes that directly affected competing crops, thereby indirectly changing the relative position of pigeonpea. Therefore, when I describe the marketing of pigeonpeas in India, I will address the present situation of production and demand in the light of past changes and of the price and income elasticities that measure the degree to which changes in demand and supply can be expected, given certain changes in income and prices.

The salient features of market channels for pigeonpeas and an overview of the market prices over time and space describe the ways in which the pigeonpea market operates.

Based on the efficiency and reliability of price formation in the pigeonpea markets, a method is proposed of analyzing market prices to derive information on consumer preferences for certain quality characteristics of pigeonpeas.

Production

Pigeonpea grown on about 2.5 million ha, occupies about 11% of the total area under all pulses in India (Table 1). Maharashtra, Uttar Pradesh, and Madhya Pradesh are the major pigeonpea-producing states, each contributing about 20% of the area under pigeonpea.

Over the past 20 years there have been shifts in the area under pigeonpea in different states

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Table 1. Percentage of various puise crops in total pulse area in India.

Pulse crop	1950-51	1960-61	1971-72
Rabi Pulses			
Chickpea	40.87	38.44	36.46
Khesari		8.12	7.58
Masur		3.22	3.33
Pea		4.77	4.11
Total rabi pulses		54.55	51.48
Kharif Pulses			
Pigeonpea	11.77	10.11	10.55
Urd		7.20	8.07
Mung		6.35	7.70
Moth		5.86	7.94
Kulthi		6.55	7.73
Total kharif pulses		36.07	41.99
Other pulses		9.40	6.54

Source: Chopra and Swami 1975.

(see Table 2); while the north central states of Madhya Pradesh, Rajasthan, and Gujarat have been increasing their relative share in area together from 21% in 1954-57 to about 25% in 1972-75, the contribution from Uttar Pradesh has fallen from 27% to 21% of the area under pigeonpea. Thus, pigeonpea cultivation has been moving from the north to the north central states. In the southern states of Karnataka and Tamil Nadu, pigeonpea production has increased: in Karnataka primarily due to yield increases, and in Tamil Nadu primarily due to area increases (Table 3). These shifts have taken place despite the fact that the yields in Uttar Pradesh of 1106 kg/ha in 1972-75 were considerably higher than the yields in Madhya Pradesh of 763 kg/ha (Table 4). Clearly, pigeonpea was more competitive in loweryielding Madhya Pradesh than in high-yielding Uttar Pradesh, where other competing crops such as wheat displaced both pigeonpea and chickpea. In addition, restrictions imposed upon the

Tabla 2. Area under plgeonpea in selected states of India over time ('000 ha).

State	1954-57	1958-61	1968-71	1972-75
Punjab and Haryana			10.7 (0.4)[a]	5.5 (0.2)
Uttar Pradesh	633.2 (27.1)	651.2 (26.6)	590.0 (22.5)	537.4 (21.2)
Rajasthan	14.6 l.6)	22.9 (.9)	24.6 (.9)	30.4 (1.2)
Gujarat	80.9 (3.4)	82.6 (3.4)	90.3 (3.4)	91.8 (3.6)
Madhya Pradesh	388.2 (16.7)	386.1 (15.8)	496.1 (18.9)	519.7 (20.5)
Maharashtra	533.1 (22.9)	542.8 (22.2)	634.1 (24.2)	572.4 (22.6)
Andhra Pradesh	158.3 (6.8)	151.5 (6.2)	183.1 (7.0)	196.5 (7.8)
Karnataka	271.8 (11.6)	292.0 (11.9)	285.4 (10.9)	266.3 (10.5)
Tamil Nadu	57.7 (2.4)	57.2 (2.3)	55.1 (2.1)	93.8 (3.7)
All India	2328 (100)	2445 (100)	2617 (100)	2537 (100)

a. Figures in parentheses indicate percentages.

Tabla 3. Production of pigaonpaas in selected states of India ovar time ('000 tonnes).

State	1954-57	1958-61	1968-71	1972-75
Punjab and Haryana			5.0 (0.3)[a]	3.0 (0.2)
Uttar Pradesh	858.9 (46.2)	767.3 (42.1)	695.2 (37.6)	594.3 (34.6)
Rajasthan	4.4 (0.2)	6.6 (0.4)	9.6 (0.5)	11.1 (0.7)
Gujarat	40.8 (2.1)	39.6 (2.2)	42.4 (2.3)	37.7 (2.2)
Madhya Pradesh	293.9 (15.8)	308.9 (16.9)	345.6 (18.7)	296.6 (23.1)
Maharashtra	397.6 (21.4)	370.8 (20.3)	320.2 (17.3)	311.2 (18.1)
Andhra Pradesh	44.6 (2.4)	47.7 (2.6)	77.8 (4.2)	40.9 (2.4)
Karnataka	88.5 (4.7)	92.0 (5.0)	133.9 (7.2)	122.9 (7.2)
Tamil Nadu	23.7 (1.2)	25.3 (1.4)	21.7 (1.2)	39.1 (2.3)
All India	1856 (100)	1823 (100)	1847 (100)	1718 (100)

a. Figures in parentheses indicate percentages.

Table 4. Plgeonpea yiekds (kg/ha) in selected statea of India ovar four tima parioda.

State	1954-57	1958-61	1968-71	1972-75
Punjab and Haryana			467	545
Uttar Pradesh	1356	1178	1161	1106
Rajasthan	301	288	390	365
Gujarat	504	121	470	411
Madhya Pradesh	757	800	697	763
Maharashtra	746	683	505	544
Andhra Pradesh	281	315	425	208
Karnataka	326	315	469	462
Tamil Nadu	411	442	394	417
All India	797	746	706	677

movement of pulses out of Uttar Pradesh in 1965 (von Oppen 1978a) would have depressed prices considerably, which further induced farmers to shift out of pulse production in Uttar Pradesh, while at the same time in Madhya Pradesh, Rajasthan, and Gujarat, pigeonpeas became comparatively more advantageous to grow.

Area and production of pigeonpeas and other pulses respond to prices. Preliminary results of a study under way at Yale University (H. P. Binswanger, personal communication) show that the price elasticity of pigeonpea supply is probably in the order of 0.5; that is, a 10% increase in the price would cause a 5% increase in production.

Consumption

Pigeonpeas, like other pulses in India, are consumed primarily as dhal. There are no separate estimates of the behavior of consumers of pigeonpeas but only estimates of the demand for all pulses in the form of dhal. These estimates indicate an overall income elasticity of demand of 0.6 (Chopra and Swami 1975). Radhakrishna and Murty (1980) estimate income elasticity to be above 1.0 in the lower income classes and less than 0.5 in the higher income groups.

Own-price elasticities of demand for pulses are in the order of -0.6 and the cross-price elasticity with cereals is 0.65, again with higher elasticities in low-income groups and lower ones in higher income groups. This shows that the Indian consumer responds to higher pulse prices with lower consumption and that he regards cereals as relatively good substitutes, the 10% decrease of cereal prices causing a decrease in pulse consumption by 6.5% and vice versa (Chopra and Swami 1975).

Market Channels

Pigeonpeas are primarily grown for home consumption in India. Estimates from various studies indicate that only about 35% of the production is sold in regular market channels and 65% remains within the villages.[1] The major part of this amount is used for home consumption.

Detailed data collected from six villages under study since 1975 in Andhra Pradesh and Maharashtra show for the three years from 1975-76 to 1977-78 the variability of pigeonpea production and sales from year to year and from village to village (Table 5).

Marketing Study of Pigeonpeas

Only about one-third of pigeonpea production flows into regular market channels. In a marketing study of ICRISAT crops, 29 markets were randomly selected in the semi-arid tropical areas in India. The major results of this study for pigeonpeas are reported below.

MARKET CHANNELS. As depicted in Figure 1, 35% of pigeonpea production enters primary wholesale markets and 65% is retained on the farm. Of the 35% entering the primary wholesale markets, 10% is destined for local dhal mills, 20% arrives at secondary wholesale markets and mills, and 5% is shipped to terminal markets and mills. The other 65% retained on the farm is used for home consumption, seed, and for payment in kind.

PRODUCER'S SHARE IN CONSUMER'S RUPEE. The study of three markets in Andhra Pradesh shows that about 78% of the consumer rupee goes to the farmer (Table 6).

1. V. T. Raju and M. von Oppen, Marketing efficiency for selected crops in semi-arid tropical India, ICRISAT Economics Program paper, Patancheru, A.P., India.

Table 5. Pigeonpea production and sales per household in sescted villages in India by iand holding class beteen 1975-76 and 1977-78.

Land holding class	1975-76			1976-77			1977-78		
	Total prod. (kg)	Total sales (kg)	Propor-tion sold (%)	Total prod. (kg)	Total sales (kg)	Propor-tion sold (%)	Total prod. (kg)	Total sales (kg)	Propor-tion sold (%)
Aurepalle, Mahbubnagar, Andhra Pradesh									
Landless	0	0	0	0	0	0	0	0	0
Small	415	0	0	25	6	22	78	12	15
Medium	310	0	0	90	11	12	101	6	6
Large	1288	150	12	15	18	120*	208	30	14
Dokur, Mahbubnagar, Andhra Pradesh									
Landless	0	0	0	0	0	0	0	0	0
Small	65	0	0	0	0	0	0	0	0
Medium	300	150	50	0	0	0	0	0	0
Large	890	10	1	0	0	0	445	0	0
Shirapur, Sholapur, Maharashtra									
Landless	0	0	0	0	314	0	0	0	0
Small	0	0	0	341	319	94	0	5	0
Medium	1221	175	14	370	738	199*	10	24	240*
Large	1 235	175	14	1903	2 507	132[a]	0	82	0
Kalman, Sholapur, Maharashtra									
Landless	0	4	0	0	20	0	0	0	0
Small	452	7	2	568	414	73	396		
Medium	306	125	41	639	696	109*	1 102		
Large	404	140	35	1443	1416	98	1 138	60	5
Kanzara, Akola, Maharashtra									
Landless	0	0	0	0	24	0	0	0	0
Small	670	192	29	220	87	40	573	54	9
Medium	1 515	629	42	800	714	89	494	104	21
Large	5 583	2 554	46	2 626	1 288	49	2 854	1477	52
Kinkheda, Akola, Maharashtra									
Landless	0	0	0	0	0	0	0	0	0
Small	898	361	40	417	90	21	672	36	5
Medium	2 347	636	27	839	616	73	756	108	14
Large	5 450	2 136	39	2 373	3 194	135[a]	4981	718	14
All villages									
Landless	0	4	0	0	358	0	0	0	0
Small	2 500	560	22	1571	915	58	1719	106	6
Medium	5 999	1715	29	2 738	2 775	101*	2 463	242	10
Large	14850	5 165	35	8360	8 413	101*	9 626	2 501	26
All farmers[b]	23 349	7 440	32	12 669	12113	96	13 808	2 849	21

a. Sales may exceed production In years when the previous year's production is also sold.
b. Excluding labor.

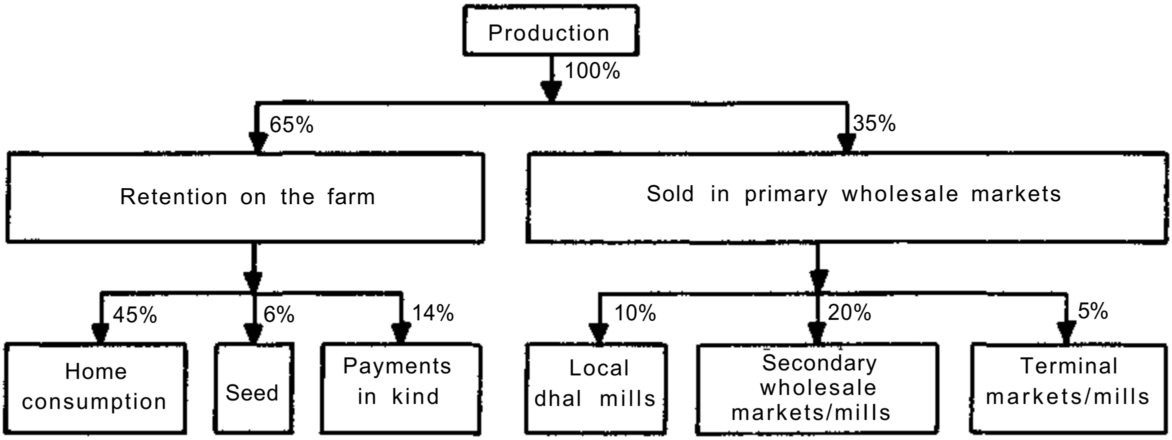


Figure 1. Estimates of flows of pigeonpea through different channels, 1974-75.

Table 6. Average estimates of marketing margins in three markets[a] for pigeonpeas, 1975—76.

Trade level	Marketing margin (Rs/100 kg)
Wholesale trader's level	
Gross margins	17.59
	(6.87)[b]
Net margins	6.76
	(2.64)
Miller's level	
Gross margins	22.56
	(8.81)
Net margins	11.54
	(4.51)
Retailer's level	
Gross margins	12.27
	(4.79)
Net margins	7.67
	(3.00)
Farmer's net price	200.13
	(78.16)[c]
Consumer's price	256.04
	(100)

a. Warangal, Khammam, and Tandur in Andhra Pradesh.
b. Figures in parentheses are percentages of consumer price - 100.
c. Farmers' share In consumer's rupee.

INTERREGIONAL TRADE. Pigeonpeas are being shipped over longer distances from primary markets than are cereals (Figs. 2 and 3).

PRICING EFFICIENCY. Using correlation coefficients of weekly prices of one year as an indicator for pricing efficiency, we find that pricing efficiency for pigeonpeas is relatively high (Table 7).

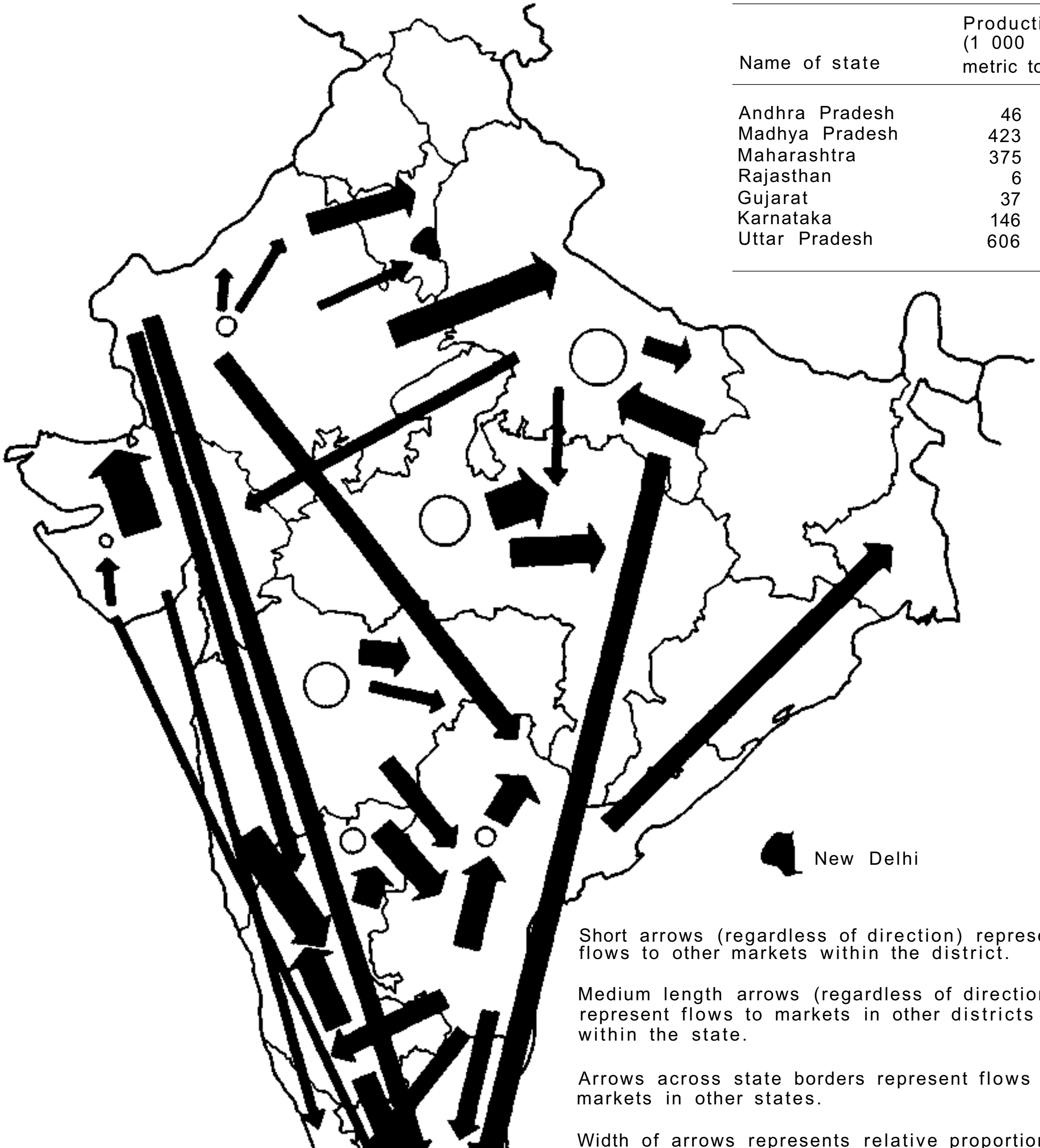
PRICE CORRELATIONS IN PIGEONPEA MARKETS. Price correlations vary between pairs of markets in different regions (Table 8). Generally, higher correlation coefficients are found for larger markets in major producing zones.

The overall finding of this study was that in comparison with markets for sorghum, pearl millet, and chickpea, markets for pigeonpea are generally competitive and efficient in both operation and in pricing.

Prices over Space and Time

Price Index of Pigeonpeas

Pigeonpea prices have been increasing rapidly over the past 15 years and at a faster rate than cereal prices (Fig. 4). In view of the estimated elasticities reported above, this price development is explained by supply and demand,



Name of state	Production (1 000 metric tons)
Andhra Pradesh	46
Madhya Pradesh	423
Maharashtra	375
Rajasthan	6
Gujarat	37
Karnataka	146
Uttar Pradesh	606

Short arrows (regardless of direction) represent flows to other markets within the district.

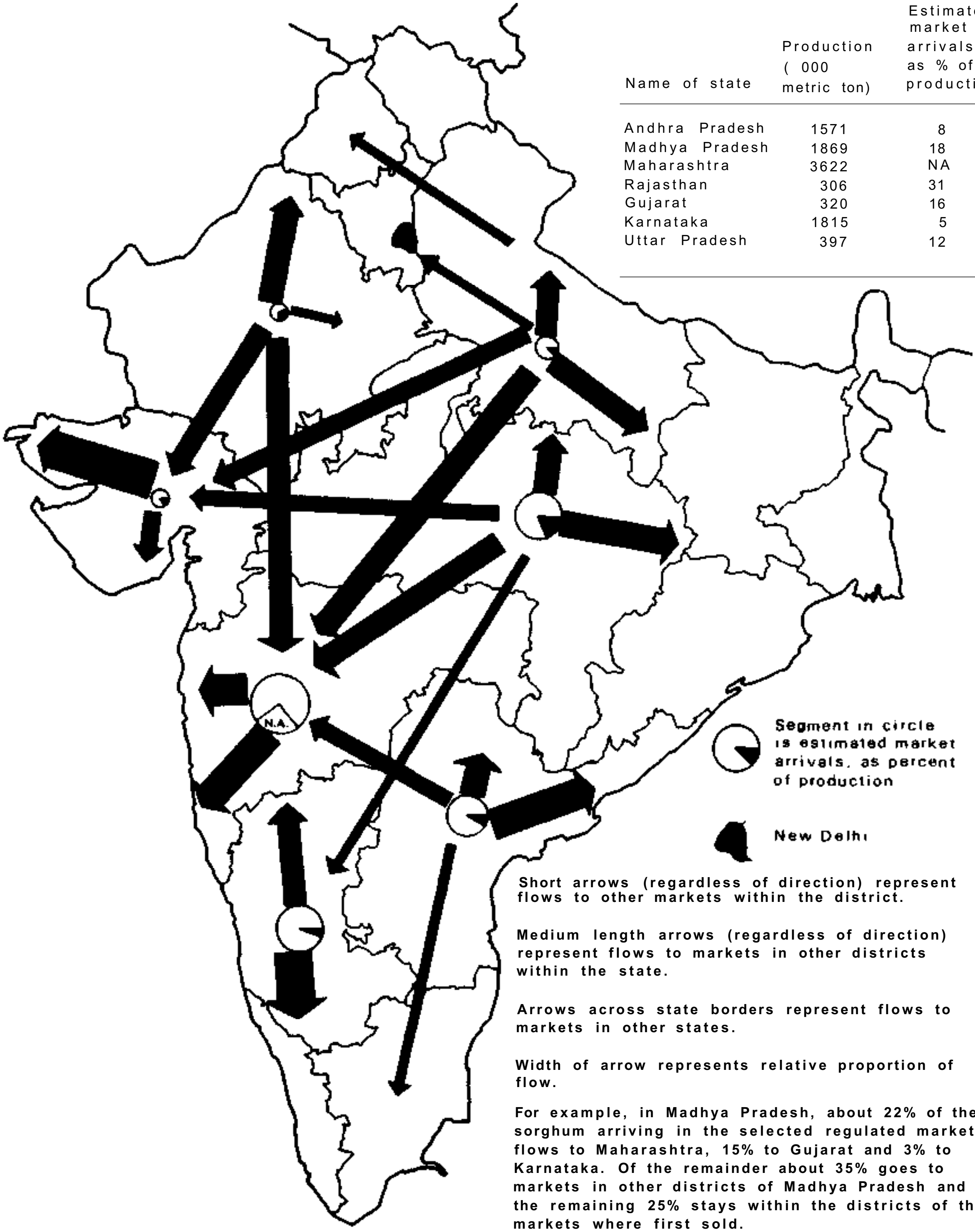
Medium length arrows (regardless of direction) represent flows to markets in other districts within the state.

Arrows across state borders represent flows to markets in other states.

Width of arrows represents relative proportion of flow.

For example, in Uttar Pradesh, about 30% of the pigeonpea arriving in the selected regulated markets flows to Tamil Nadu, 7% to Gujarat and 6% to Madhya Pradesh. Of the remainder about 40% goes to markets in other districts of Uttar Pradesh and the remaining 17% stays within the districts of the markets where first sold.

Figure 2. Production of pigeonpea and total flows, as percent of market arrivals, from selected foodgrain markets in selected states of India, 1974-75.



Name of state	Production (000 metric ton)	Estimated market arrivals as % of production
Andhra Pradesh	1571	8
Madhya Pradesh	1869	18
Maharashtra	3622	NA
Rajasthan	306	31
Gujarat	320	16
Karnataka	1815	5
Uttar Pradesh	397	12

Short arrows (regardless of direction) represent flows to other markets within the district.

Medium length arrows (regardless of direction) represent flows to markets in other districts within the state.

Arrows across state borders represent flows to markets in other states.

Width of arrow represents relative proportion of flow.

For example, in Madhya Pradesh, about 22% of the sorghum arriving in the selected regulated markets flows to Maharashtra, 15% to Gujarat and 3% to Karnataka. Of the remainder about 35% goes to markets in other districts of Madhya Pradesh and the remaining 25% stays within the districts of the markets where first sold.

Figure 3. Production of sorghum, market arrivals as percent of production, and total flows as percent of market arrivals from selected foodgrain markets in selected states of India, 1974-1975.

Table 7. Correlation coefficients of weekly wholesale prices of pigeonpea in selected markets in India, 1974-76.

Market	Warangal	Indore	Poona	Nadbai	Patan	Bagalkot	Shahabad
Warangal (116)[a] Andhra Pradesh	1	0.96* (41)[b]	0.93* (31)	0.68* (17)	0.39* (31)	0.79* (41)	0.92* (32)
Indore(184)[a] Madhya Pradesh		1	0.91** (42)	0.60** (18)	0.54** (38)	0.91** (52)	0.91** (43)
Poona(136)[a] Maharashtra			1	0.30 (9)	0.72** (30)	0.85** (42)	0.87** (34)
Nadbai(14)[a] Rajasthan				1	0.70** (16)	0.85** (42)	0.85** (17)
Patan (52)[a] Gujarat					1	0.77** (18)	0.63** (35)
Bagalkot (84)° Karnataka						1	0.89** (43)
Shahabad (33)[a] Uttar Pradesh							1

a. Figures in parentheses indicate size in '000 tonnes.
b. Figures in parentheses are number of nonzero paired observations.
** Significant at 1% level.
* Significant at 5% level.

showing that the decrease in per capita net availability (Fig. 4) of pulses as compared with a slightly increasing availability of cereals has moved up pulse prices, especially pigeonpea prices. At the same time, a slight increase in per capita income also contributed to the price increase.

Seasonal Prices of Pigeonpeas

A study of monthly prices of the years 1970 to 1976 shows that seasonal price variation on average has a peak in November-December and a low in April (Fig. 5). The increase from the lowest to the highest price is 13% in 7 months. As the seasonal price variation generally reflects storage costs, this moderate price increase of about 2% a month would be an indication of relatively moderate storage costs and storage losses.

Regional Price Variation

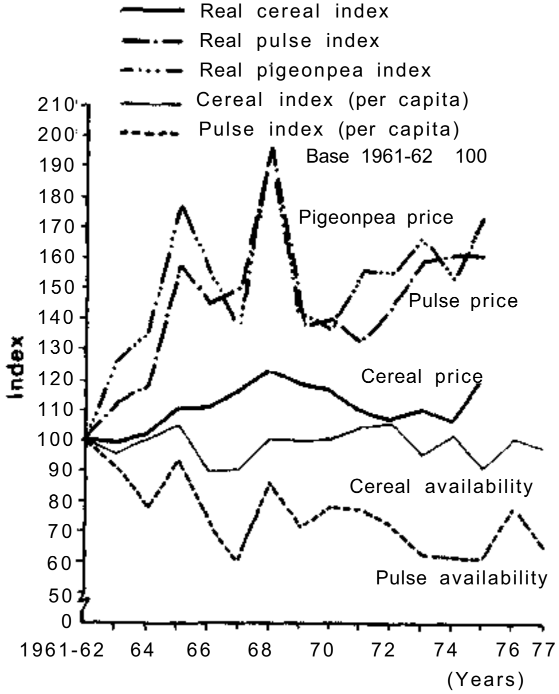
Taking 19 years' average prices for pigeonpeas in 94 districts, we find typical low and high price regions (Fig. 6). There is ageneral pricegradient from Tamil Nadu and Karnataka, which havethe highest prices, towards Madhya Pradesh with lower prices. Unfortunately, this information is not available for Uttar Pradesh and Bihar. Here the prices are expected to be the lowest, due to the restrictions on pulse exports from these states that were in force between 1966 and 1968. This price gradient from north to south again explains the shifts in area and productivity of pigeonpeas along this gradient that we have observed over the past two decades.

Within states, adjacent districts may show considerable price differences; for instance in Andhra Pradesh the Telengana districts (e.g. Mahbubnagar, Medak, Adilabad) have for the 19 years shown higher pigeonpea prices than those of Rayalseema (e.g. Kurnool, Anantapur, Cuddapah). Differences in quality may be the cause for these price differentials. The price difference between East and West Godavari, which did not exist before 1964, is also interesting: prices east of the Godavari river fell to significantly lower levels only between 1964 and 1973, when foodgrain trade restrictions

Table 8. Correlation coefficients of weekly market prices of selected crops among three selected markets and between each of these and 28 other markets in 1974–75.

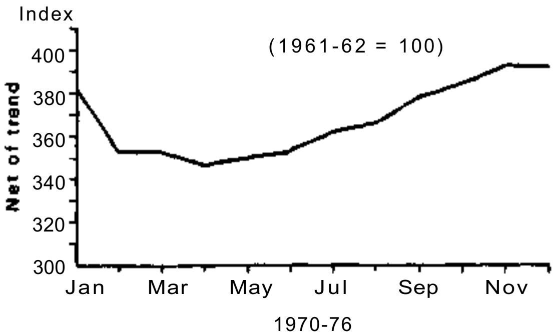
Market	Sorghum			Pearl Millet			Pigeonpea			Groundnut			Average[a]
	WGL	KMM	TDR	WGL	KMM	TDR	WGL	KMM	TDR	WGL	KMM	TDR	
Warangal (WGL)	1	0.30*	0.40*	1	0.93**	0.91**	1	0.96**	0.85**	1	0.62**	0.59**	0.47
Khammam (KMM)		1	0.88**		1	0.90**		1	0.94**		1	0.72**	0.55
Tandur (TDR)			1			1			1			1	0.58
Average[b]	0.35*	0.58**	0.38*	0.56**	0.75**	0.59**	0.74**	0.71**	0.79**	0.25**	0.18	0.56**	

a. Average across four crops of average price correlation coefficients with 28 other markets.
b. Average of price correlation coefficients between selected and 28 other markets.
** Significant at 1% level.
* Significant at 5% level.



Source: Government of India. Bulletin of food statistics. Various issues.

Figure 4. Indices of real prices and of per capita availability of cereals, pulses, and pigeonpeas in India.



Source: Government of India. Bulletin of food statistics. Various issues.

Figure 5. Average monthly detrended index prices of pigeonpeas in India (1970-1976).

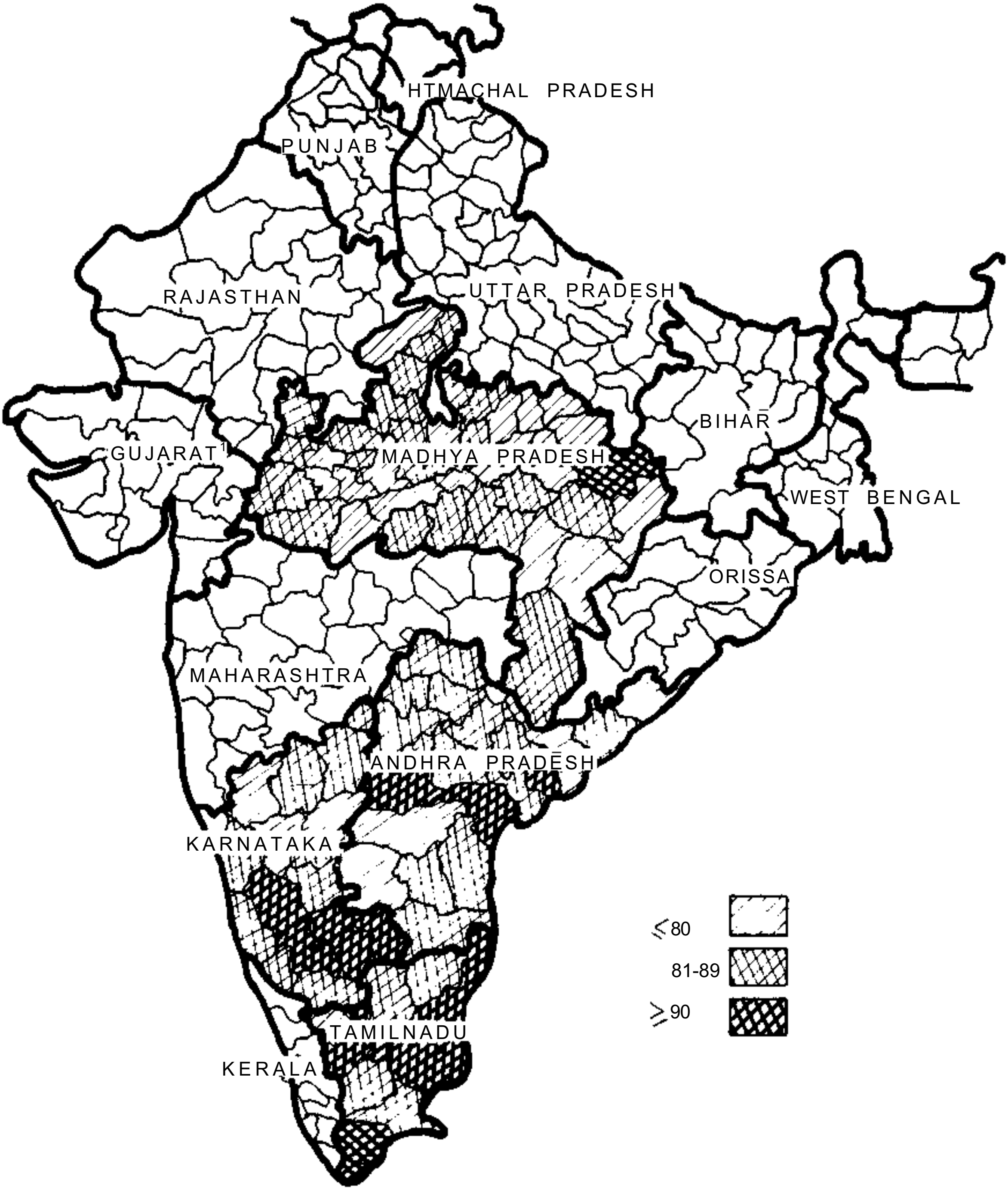


Figure 6. Average pigeonpea prices in selected states (district averages over 19 years from 1957to 1975 in rupees/100 kg).

were strongly enforced. In Karnataka, the districts south and east of Shimoga and Chitradurga show traditionally higher prices than those in the north such as Dharwar, Raichur, and Belgaum. In Madhya Pradesh, there seems to be a low-price region in the central districts, which did not exist before 1964 but which formed during 1964-73, probably under the influence of restrictive trade policies, when higher prices in neighboring states (e.g. Maharashtra, Gujarat, and Rajasthan) might have exercised additional demand for pigeonpeas from the bordering districts of Madhya Pradesh. Some of the price differences from district to district may however be due purely to differences in the quality of the pigeonpeas.

Quality as a Determinant of Price

On any market day, prices of pigeonpeas in different lots transacted during that day depend upon the quality of a particular lot. Following a methodology developed for sorghum (von Oppen 1976), we have tried to explain this price variation within a market day as a function of a number of possibly relevant quality characters by using multivariate regression analysis. The results of this study (see also von Oppen 1978b) are summarized as follows:

- White color is associated with higher prices.
- 100-seed weight has no significant effect upon price.
- Increase in volume after6 hours of soaking in water is significantly and positively affecting price.
- Protein content tends to have a nonlinear relationship with an optimum around the average.
- The reported recovery rate of dhal from pigeonpeas has a very strong effect on prices. Unfortunately, there was no objective measure of the recovery potential, and we had to rely on millers' report.
- The rate of insect damage in our sample showed positive association with prices, damage being greater in higher priced dhal. Apparently insects and human consumers have similar preferences.

Conclusion

Our study of the marketing of pigeonpeas in India shows that pigeonpea markets are functioning relatively well, even though on average only about 35% of the production appears in the formal market channels. The prices formed in these markets convey a consistent picture: both pigeonpea producers and consumers respond to changes in prices. Following the introduction of new technology for competing crops, especially for wheat in north India, along with movement restrictions on foodgrains, which reduced the comparative advantage of pigeonpeas in those states, pigeonpeas have moved over the past 20 years from the north towards the central states and the south. The north central states have increased the area under pigeonpeas and thereby expanded production. In the southernmost states, production of pigeonpeas has considerably increased due to increased pigeonpea yields in Karnataka and increased area in Tamil Nadu.

Analysis of market prices as a function of quality characteristics indicates that high prices are associated with white seed color, good swelling capacity, and high recovery rates in dhal milling.

In view of the efficient functioning of pigeonpea markets and the relaxing in 1977-78 of interregional trade restrictions for most agricultural produce in India, we can expect that the process of north-south movements of pigeonpea may possibly be halted or reversed. In the absence of price distortions, shifts in supply response will reflect true locations of comparative advantage. As long as the policy lasts, the readjustment may turn out to be quite intensive. This is expected to also lead to higher aggregate production of pigeonpea in India; where yields and prices are such that returns from pigeonpeas exceed those from other competing crops, farmers will further emphasize the pigeonpea component in their cropping patterns: conversely, farmers in areas where pigeonpea shows no advantage may reduce its proportion in the intercrop. Following this principle, relatively small adjustments can bring about substantial increases in overall productivity (von Oppen 1978a) especially of pulse crops such as pigeonpeas, which are relatively valuable and therefore highly transportable and at the same time fairly location specific in their yield performance. However, in the long run, India needs new varieties that are expected to come out of breeding programs: early-maturing, disease-resistant, high-yielding varieties, which will then beproduced wherever best suitable at substantially lower costs and in larger quantities to the farmer's benefit.

Acknowledgment

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References

CHOPRA, KUSUM., and SWAMI, GURUSHRI. 1975. Pulses: an analysis of demand and supply in India 1951-1971. New Delhi, India: Sterling Publishers.

GOVERNMENT OF INDIA. (Appropriate years.) Bulletin of food statistics, New Delhi, India.

RADHAKRISKNA, R., and MURTY, K. N. 1980. Models of complete expenditure systems for India. International Institute for Applied Systems Analysis working paper. A-2361, Laxenburg, Austria.

VON OPEN, M. 1976. Consumer preferences for evident quality characters of.sorghum. Presented at the Symposium on Production, Processing and Utilization of Maize, Sorghum, and Millets. Central Food Technological Research Institute, 27-29 Dec 1976, Mysore, India.

VON OPPEN, M. 1978a. The effects of interregional trade and market infrastructure on aggregate productivity of agriculture. ICRISAT Economics Program paper, Patancheru, A.P., India (Mimeographed).

VON OPPEN, M. 1978b. An attempt to explain the effects of consumer's quality preferences on prices of foodgrains at different levels of productivity. ICRISAT Economics Program discussion paper 8, Patancheru, A.P., India (Mimeographed).

Processing and Marketing of Green Pigeonpeas: the Case of the Dominican Republic

George Mansfield R*

Abstract

In the Dominican Republic, pigeonpea is grown mainly on small farms of less than 2 ha. About 80% of the annual harvest is exported, in the form of canned or frozen green peas. This paper describes the processing techniques used in the country and the procedure followed for marketing the product, which goes chiefly to the Latin American population in the large cities of the United States.

Although great strides are being made in certain regions of the Dominican Republic in the cultivation of pigeonpea on a large scale, the majority of the farms growing this crop are still on the average not more than 2 ha.[1]

The main impetus for the increase in cultivation has come from the export market, whose demand for canned pigeonpeas has doubled since 1970 to the 1978 level of about 340 000 cases (16-oz cans). At present, close to 80% of the annual harvest is exported.

According to studies made by the Ministry of Agriculture, the total area dedicated to pigeonpea in 1976 was 13 941 ha, with an average yield of about 2000 kg/ha. Prices at the farm level are dependent on the availability of the product during certain periods or seasons, but they seem to have always been above the estimated production costs; for pigeonpeas produced in season, prices have risen from RD $8.50 to RD$ 11.00 per 100 lb (45 kg) during the 1973-1977 period.

Prices for the finished products exported are only available for canned green pigeonpeas, which have gone from US $5.50 for the 24-can case in 1970 to US $10.45 in 1978. Although prices for fresh green pigeonpeas are three to four times higher per weight of product sold, exports are limited, because shelled peas are extremely perishable.

Currently, the government is trying to promote the installation of a new canning facility in the high altitude region of La Sierra, in order to activate the economy of that area. Studies have shown that the total fixed investment for a canning plant with a capacity of 120 000 cases per season is about US $240 000 at 1979 prices (Kalaf 1979).

Although all marketing surveys show that the trend in the U.S. and European markets is toward frozen foods and the retortable pouch, there seems to be little evidence in the Dominican Republic that processing facilities acknowledge this fact. It is our conviction that unless more importance is given to this, future export growth will remain at a minimum.

Pigeonpea Growing and Harvesting in the Dominican Republic

Varieties Grown

Information available on the pigeonpea cultivars used in the Dominican Republic is a little confusing. It is probable thatf armers are using a mixture of the types Kaki and Saragateado, which have been used for canning in Puerto Rico for a long time. In the literature, four cultivars are mentioned[2] as being used in the Dominican Republic.

* IICA, Direccion Regional, Santo Domingo, Dominican Republic.

1. Diaz Gomez, Guandul, Secretaria Agricultura, Republica Dominicana.
2. F. Saladin and V. Vinicio Reyes, 1979, Cultivo del guandul.

1. Kaki (*Cajanus indicus flavus*)

Plant medium height	1.5 m
Color of flowers	yellow without spots
Pod color	light green
Pea color	creamy yellow
Duration	165 days

2. Pinto Villalba (*Cajanus indicus bicolor*)

Plant medium height	2 m
Color of flowers	yellow with purple spots
Pod color	dark green with purple spots
Pea color	creamy yellow with purple spots
Duration	180 days

3. UASD

Plant medium height	1.5 m
Color of flowers	yellow with purple veins
Pod color	light green
Pea color	creamy yellow
Duration	150 days

4. *Cajanus indicus* Var. *Semper florens*
   This is another variety, also called "year round", also grown in the country, Itsyield is inferior to the other three varieties and it is not recommended for commercial cultivation.

Harvesting

Harvesting has been shown to be the most important step in obtaining a high-quality pigeonpea product (Sanchez Nieva et al. 1963). Factors such as drained weight; volume, viscosity, color, and turbidity of the brine; and uniformity of pea color were found to depend on the maturity of the pigeonpeas processed (Sanchez Nieva et al. 1963).

In the Dominican Republic pigeonpeas are cultivated in small family plots less than 2 ha and are harvested by poorly trained people whose criteria for picking are based on subjective considerations of touch and size.

Harvesting is done in repeated pickings, in most cases 45 to 50 days after the flowers are in full bloom and subsequent pickings are carried out every 4 to 5 days for a period ranging from 2 to 4 weeks. Where largeareas are cultivated and labor is scarce, the system of picking only once is recommended. It has been shown that although a lower yield is obtained by this system the cost of labor for repeated picking is seldom justified (Sanchez Nieva et al. 1961).

Because production of pigeonpeas seldom reaches a level to satisfy the demand of processors, very little importance is given to the maturity of the peas in the Dominican Republic. There is little regard for quality as the aim of the processor during the harvesting season is to obtain as much pigeonpea as possible to keep the canning plant working through the season.

This relatively low-quality situation, often caused by early harvesting, has been able to continue because the marketing of peas has concentrated on the high demand created by the Latin population of American cities. The demand for quality in such population groups has remained less pronounced than in the rest of the American public.

The only case in which the uniformity of peas is at a premium is when farmers are selling for the fresh market. For this market, pickers must exercise greater care to obtain mostly mature green pigeonpeas than when harvesting for the processors of canned and frozen products.

Processing of Pigeonpeas

Vining

Once harvested, the pigeonpeas are placed in 100 lb. jute bags, to be carried to the processing centers.

In the factory the peas are removed from the bags and spread out in the areas close to the viners or where the shelling will be carried out. This will prevent the pods from being too long in a low-oxygen environment inside the bags and fermenting.

Vining is done mechanically or by hand, depending on the volume requirement of the processor and on the end product. For fresh peas packed in polyethylene bags, pigeonpeas are invariably vined by hand.

Hand vining not only requires a low capital investment for the packer of fresh pigeonpeas but also produces a much better looking product and higher yields than machine vining. Some frozen product packers also use hand vining, but usually only when they have a low-volume market. For a high-volume industrial operation, such as canning, hand vining is too costly, and machine vining is used instead.

Although most canners in the Dominican Republic feed the pods directly into the vining machine without any pretreatment, only once through, some preheat the pods to obtain better yields and have their viners arranged so that the pods from one viner are passed to a second unit for more complete removal of the peas. A practical advantage of the latter system, in addition to higher yield, is that the peas are damaged less by the viner and the brine is usually clearer due to the possible inactivation of enzyme systems by the heat (Sanchez Nieva et al. 1961).

Cleaning of Peas After Vining

The procedures for cleaning the peas after vining depend on whether they have been hand- or machine-shelled.

For the fresh market and for small freezing operations, hand shelling is also a cleaning and inspection procedure where unwanted peas and other foreign matter are rejected by the shelter. When peas have been handshelled for freezing, peas are cleaned by placing in cold water containers before blanching, so as to keep the blanching water as clean as possible. For the fresh market, peas are not washed and the only cleaning is done by the shelters themselves.

After machine vining, peas fall directly into conveyors for cleaning and washing. The first operation is to pass the shelled peas through a cleaning machine in which an air blast removes light pieces of pods or vine. The peas then drop on to a large mesh screen that all ows the peas to drop through but retains pieces of pod and other extraneous material. A second screen below has fine mesh that retains the peas but permits the passage of fine dirt and splits.

After dry cleaning, the peas are then washed in various combinations and types of flotation washers with cold running water. This washing procedure, besides cleaning the peas, also removes floating dirt, skins, split peas, and worms.

Removal of Split and Mashed Peas

After washing, peas that have been machine-vined or shelled are passed through rotary rod washers where split and undersized peas are removed from further processing.

This operation, common to all pea canning plants, is carried out mainly to remove split and mashed peas and is not really intended to remove small peas.

In the canning industry a demand has been established for what is called "mixed sieve sizes" and therefore size grading is not an important step in green pigeonpea processing as done in the Dominican Republic.

Inspection

After the automatic removal of defective peas coming from the washing station, the remaining peas fall onto picking belts (24 to 30 inches wide and 10 to 15 ft. long) where off-colored, worm-damaged, and broken peas are removed from further processing.

In some plants, peas are only inspected before blanching, but an afterblanch inspection is recommended in order to assure total removal of all extraneous material before canning.

Blanching

As with all vegetables, blanching is an essential heat treatment operation in the canning and freezing of peas. According to the available literature, the blanching is done to:

- fix the color,
- improve the flavor,
- reduce the volume and improve the texture to permit the placing of a large weight of peas in the can,
- remove a mucous substance and free starch so as to obtain a clearer brine, and
- remove intercellular gases from the pea, to lessen can strain during heating, help obtain a satisfactory vacuum, and reduce possibilities of internal can corrosion.

According to studies carried out in Puerto Rico (Sanchez Nieva et al. 1961) which have been commercially proven, the best blanching method for obtaining a clear brine is to heat the peas to 185°F for about 5 minutes in hot water and to cool right after this heating process with cool water at about 80°F.

Steam blanching has been shown to cause less shrinkage and lower losses of nutrients (Melmick et al. 1944) but present cost of energy considerations make it an undesirable alternative.

After-Blanching Procedures

After the cooling step in the blanching procedure, peas must be inspected to remove off-colored peas that do not show before blanching and to assure complete removal of foreign matter before canning or freezing. All processing steps up to this point are the same for both canning and freezing of peas.

Canning of Pigeonpeas

Figure 1 diagrams the procedure followed in canning of green pigeonpeas.

Filling

Once finally blanched and inspected, peas are transported by an elevating conveyor to a volumetric filler, which fills the can along with a 2% near-boiling brine (195-200°F). No sugar or any other additive is included.

A fill-in weight of 10.5 oz has been found to give the required net weight to satisfy the labeling requirements of the USA for the No. 303 can.

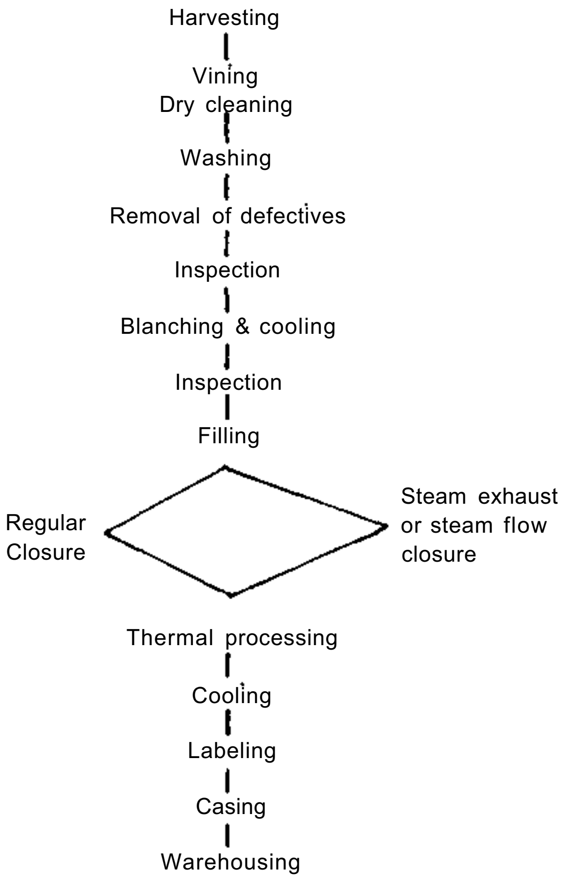

Figure 1. Pigeonpea canning procedures.

Closing

For small cans, if a near-boiling brine is maintained at the filling station, no mechanical exhaust or steam closure is required; for cans larger than the 307 x 409, an additional means of making a vacuum is needed, besides the near-boiling brine.

After closing, the cans should be thermally processed as soon as possible to inhibit the growth of thermophilic bacteria that may spoil the product later in high-temperature (100°F) warehouses.

Thermal Processing

Since most canned pigeonpeas are exported to the United States, they must conform with all regulations pertaining to low acid food products as defined in Title 21 of the CFR part 108. This requires that all plants processing low acid foods be registered with the Food and Drug Administration of the U.S. federal government, and that thermal processes used for such products be designed by competent and experienced personnel.

Table 1 shows the processing parameters recommended for the commercial sterilization of peas by the National Canners' Association of the USA.

Cooling

As with all canned products, peas must be immediately cooled after thermal processing to reduce thermal quality losses and growth of thermophilic bacteria.

The No. 303 cans are cooled in cooling channels without previous cooling in the retorts. Once the retort pressure is brought to ambient, the cans are carried to a cool water pond or channel where they are immersed until their temperature reaches the 90 to 105°F level. Cans with a diameter largerthan 3 and 7/16 in. should be pressure-cooled in the retort during the initial part of the cooling cycle to prevent undue straining of the can ends.

To save water and keep temperature at levels that will assure a prompt and safe cooling, water should be recirculated through a cooling tower or pond.

Table 1. Processing parameters for canning peas In brine.

Can Size	Maximum fill Weight (ounces)	Minimum Initial Temperature (°F)	Minutes at Retort Temperature		
			240°F	245°F	250°F
211 x 304	6.9	70	34	24	17
303 x 406	11.5	140	31	21	15
603 x 700	72.0	70	57	40	28
		140	48	32	21

Source: Bulletin 26-L, National Canners'Association, USA.

Containers

Can size used in the Dominican Republic to export pigeonpeas to American territories is the so called three-piece No. 303 can (303 x 406). The following specifications, as given by the American Can Company, are being used:

Tin coating		*Coating*		*Type of steel*
Body	End	Body	End	MR
75-25"	25	Plain	C-enamel	

a. lb. of tin per base box (3/4 lb-1/4 lb) 31630 sq. in.

This container has proven to be very successful under the tropical conditions of high humidity and temperatures found in the Dominican Republic.

Freezing of Pigeonpeas

In the Dominican Republic we have seen two methods being used in the production of frozen pigeonpeas; these differ mainly in that one method uses an automatic continuous system and the other is a more labor-intensive batch system.

With the automated system the peas, following the blanching treatment and inspection, are cooled in a conveyor with ambient temperature water, while being transported to a fluidized bed freezer. In this cooler, which operates at a temperature well below freezing (-20°F to - 10°F) the peas are individually quick-frozen (IQF) while moving inside a vibrating conveyor screen, which receives a rapid moving current of cold air from below. Once frozen, pigeonpeas are hand-packed in cartons that have been special wax-treated to prevent the dehydration of the product. Packed products are then stored at 0°F. Figure 2 gives a diagram of the freezing procedure.

The batch system is used for lower production requirements and uses a blast freezer. In this case, the peas are blanched and inspected in the usual manner and are then dropped in cold water tanks as they come out of the hot water blancher. Once cooled, the peas are hand packed in polyethylene bagsand placed in trays for freezing in a batch freezer (-20 to -10°F)for 4 to 10 hours depending on the freezer design, package size, and initial temperature of the product. Frozen pea bags are then placed in corrug ated containers for storage at 0°F. Frozen peas are transported in controlled-temperature containers to foreign markets in the USA.

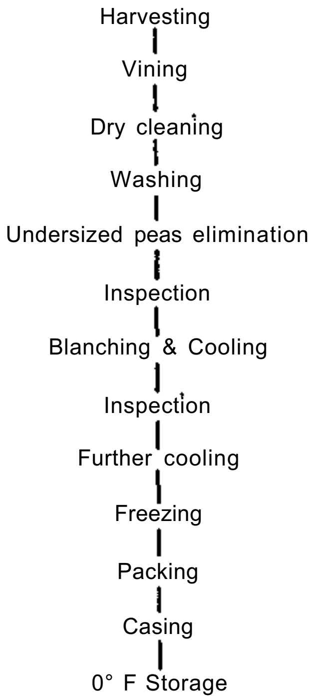

Figure 2. Pigeonpea freezing procedures.

Marketing of Pigeonpeas from the Dominican Republic

In terms of volume and dollars the most important pigeonpea product being marketed in the Dominican Republic is the canned pigeonpea in the 16 oz. No. 303 can.

Next in importance is the mature green fresh pea, packed in polyethylene bags, and last the frozen green pigeonpea in polyethylene bags or cardboard containers.

It has been estimated that the canning industry acquires more than 60% of the total Dominican pigeonpea crop, and the packers of mature green fresh peas about 15%. Frozen food processors still use only a negligible portion of the total annual crop.

Marketing of Canned and Frozen Green Pigeonpeas

The growth of pigeonpea cultivation in the Dominican Republic has been mainly due to the impulse given by canning plants moving from Puerto Rico because of the local tax and low-cost labor incentives. Industries in Puerto Rico, finding it difficult to operate there, moved very rapidly to the Dominican Republic, but found the pigeonpea production too low to satisfy the demands of their clients in Puerto Rico and in mainland USA. Thus pigeonpea began to be grown ona large scale by farmers, entirely as an export crop.

Atthe farm level pigeonpeas are sold in 100-lb bags to intermediaries who collect in a small area the production of, say, 15 to 20 farmers. These intermediaries sell in turn, in most cases, to representatives of the canning plants. These representatives are responsible for arranging the transportation and for contracting with intermediaries to secure as much raw material as possible.

At the export level, most can ners have their production generally sold beforehand to a distributor-wholesaler with whom they have developed a very close relationship. In most instances, distributors own a part of the shares of the canning facilities. Sales of canned green pigeonpeas are made under an irrevocable letter-of-credit arrangement opened in favor of the exporter, to be paid when the goods arrive on U.S. territory and pass the Food and Drug

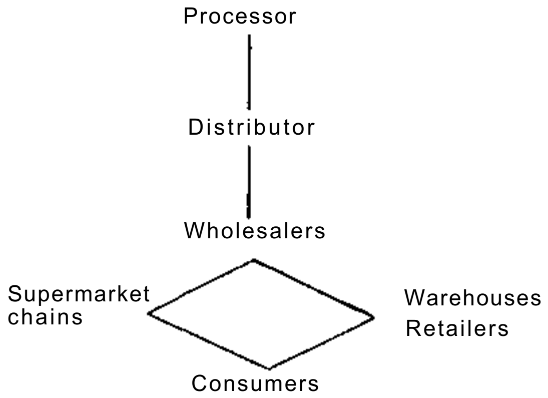

Figure 3. Distribution channel for processed pigeonpea exported from the Dominican Republic.

Administration inspection.

Frozen green pigeonpeas must be sold on consignment to a broker, who in turn sells to wholesalers or supermarket chains. This arrangement places a high risk on the exporter, who must be responsible for the product up to the point when it gets to the broker's warehouses.

Processed green pigeonpeas are almost exclusively sold to distributors who have their own brand names under which they sell various products, usuallydirected at theLatin American market in big U.S. cities (Figure 3).

Few processors sell under their own brand names, although some with known local brand names try to reach the Dominican population in the large eastern cities of the USA.

Under present conditions, processors depend heavily on their capacity, or luck, to find an aggressive distributor who has a brand name with a wide appeal among consumers.

References

KALAF, S. 1979. Estudio para la elaboracion de una planta enlatadora de guandules. INDOTEC.

MELMICK, D., HACHBERG, M., and OSER, B. L. 1944. Comparative study of steam and hot water blanching. Food Research 9: 148-153.

SANCHEZ NIEVA, F. 1963. Variations in maturity of pigeonpeas during the harvesting period. University of Puerto Rico Agricultural Experiment Station Bulletin 170, Mayaguez, Puerto Rico.

SANCHEZ NIEVA, F., and COLOMCOVAS, G. 1964. Advantages to the farmer of harvesting all the pods of pigeonpeas simultaneously. University of Puerto Rico Agricultural Experiment Station Bulletin 181, Mayaguez, Puerto Rico.

SANCHEZ NIEVA, F., RODRIGUES, A. J., and BENERO, J. R. 1961. Improved methods of canning pigeonpeas. University of Puerto Rico Agricultural Experiment Station Bulletin 157, Mayaguez, Puerto Rico.

SANCHEZ NIEVA, F., et al. 1963. The brine-grading of pigeonpeas. Journal of Agriculture of the University of Puerto Rico 47(1): 14-23.

Grain Quality of Pigeonpea

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Abstract

From the utilization point of view, the grain quality of pigeonpea is very important. The progress that has been made in identifying cultivars containing high protein, the procedures that are being employed to determine the limiting amino acids, and the levels of some of the antinutritional factors that are present in pigeonpea have been described. The relationship between the physicochemical characteristics and cooking time of pigeonpea dhal samples is described. The results of a survey of consumers and mill owners, that was conducted in major pigeonpea producing states of India are discussed.

India produces over 90% of the world's total of pigeonpea and this provides a necessary protein supplement to the largely cereal-based diet of the Indian population. In India, pigeonpea is consumed mostly in the form of decorticated split cotyledons known as dhal, while in other semi-arid tropical countries of the world such as the Caribbean Islands it is consumed in the form of green peas. Although increasing the yield and its stability are of obvious priority, grain quality also deserves consideration in a breeding program.

The grain quality of a crop has several components, including nutritional quality, antinutritional factors, digestibility and bioavailability of nutrients, cooking quality, consumer acceptability, and storage stability. The progress that has been made in studies of some components of grain quality at ICRISAT is reported in this paper.

Nutritional Quality

Protein Quantity

One of the recommendations in the plenary session of the earlier International Workshopon Grain Legumes, held at ICRISAT in 1975, was that the yield be expressed in terms of protein per unit area of land per unit of time. Then increasing the yield at constant protein content or selecting genotypes of superior protein content with average yield capability would be advantageous. A method for the determination of the protein content using the Technicon auto analyzer has been standardized (Singh and Jambunathan 1981). The precision of the method was routinely monitored by including check samples with every analysis. The coefficient of variation (CV) of analysis of check samples varied between 1.30 and 2.34%. In the initial stages, breeders also included hidden blind samples along with the routine samples for analysis. The mean protein content of pigeonpea dhal is about 23%. Analyses of germplasm accessions of pigeonpea seed revealed that the protein content ranged from 15.5 *to* 28.6% (Table 1), indicating the possibility of some high protein sources. However, the results include the analyses of samples that

Table 1. Analyses of plgaonpea germplasm aocessions for protian content.

Year	No. of samples	Percent protein (N x 6.25) Range	Mean
1975-76	1745	16.3-28.0[a]	21.0
1976-77	1087	19.1-28.6*	22.8
1877-78	1867	15.5-26.8[b]	19.6
1978-79	964	16.8-25.9*	20.5

a. Dhal. *b.* Whole seed.

* Biochemists, ICRISAT.

were obtained from unreplicated trials, and no attempt was made to study the influence of environmental or seasonal effects on protein content. Another source of high protein was identified in the wild species. Some of the species of *Atylosia,* a related genus, were found to have higher protein levels (Reddyetal. 1979). Intergeneric lines from crosses of T-21 and *Atylosia* species showed that a few lines had more than 30% protein. Amino acid profiles of pigeonpea and *Atylosia* species revealed no important differences in any of the essential amino acids.

Protain Quality

Methionine, cystine, and tryptophan are the important amino acids that are deficient (limiting) in grain legumes. Twenty-four pigeonpea dhal samples were analyzed for methionine and cystine by performic acid oxidation procedure. The total sulfur amino acid content as a percentage of protein ranged from 1.76 to 2.55%, with a mean of 2.11%. When these values were used to calculate the chemical score

$$\frac{\text{mg of amino acid in 1 g of test protein}}{\text{mg of amino acid in reference pattern}} \times 100,$$

the chemical scores ranged from 50 to 7 3, with a mean of 60.

Attempts were made to identify suitable rapid procedures for the estimation of methionine and cystine. The relationship between sulfur and sulfur amino acids was studied. Total sulfur was determined using a Leco sulfur analyzer and by using the wet digestion procedure. A comparison showed that the amount of sulfur in sulfur amino acids accounted for 75.5% of total sulfur in pigeonpea, and the individual values ranged from 59.2 to 84.6%. Table 2 shows the correlation coefficients among protein, cystine, methionine, total sulfur, and cystine plus methionine. The correlation coefficient between protein content and sulfur amino acids when expressed as percent protein was negative but insignificant. The correlation coefficient between total sulfur as percent of sample and methionine and cystine as percent of protein was positive and highly significant (r = 0.65**), indicating the possibility of using total sulfur content as an index of sulfur amino acids in pigeonpea.

The presence of S-methyl-L-cystine in pigeonpea seeds has been reported by earlier workers (Evans and Boulter 1975). It would be useful to pursue other modified methods such as the removal of S-methyl-L-cystine using ethanol, in order to study if the correlation between sulfur and sulfur amino acids could be further improved. Also, methionine and cystine when expressed as percent of protein were correlated (r=0.78**) with each other, indicating some possibilities of screening for either of these two amino acids when samples are many and the facilities are limited.

Protein fractionation studies of one cultivar of pigeonpea (HY-3C) showed that of the four protein solubility fractions, albumin, which accounted for less than 10% of total nitrogen, had the highest concentration of cystine and methionine as percent of protein. The globulin fraction, comprising about 65% of total nitrogen, had less than half the concentration of

Table 2. Correlation coafflclents among protein, total sulfur, and sulfur amino acids in plgeonpea cultivars.

	Protein (%)	Cystine (g/100 g sample)	Methionine (g/100 g sample)	Cystine + Methionine (g/100 g sample)	Cystine (g/100 g protein)	Methionine (g/100 g protein)	Cystine + Methionine (g/100 g protein)
Protein (%)		0.269	0.489*	0.392*	-0.308	-0.262	-0.214
Total sulfur (g/100 g sample)	-0.150	0.554**	0.453*	0.534**	0.616**	0.612**	0.661**
Cystine (g/100 g protein)						0.780**	0.958**

a. Based on analyses of 24 dhal amplea.

these amino acids when compared with albumin. The glutelin fraction seems to be moderately high in these amino acids, while the prolamine fraction contained relatively small amounts of sulfur amino acids. If a similar trend is obtained in other cultivars, then it would be useful to identify pigeonpeas containing normal protein levels but with a higher proportion of albumin and glutelin fractions.

Tryptophan, which is another amino acid of nutritional importance in pigeonpea, is destroyed during acid hydrolysis and hence cannot be determined along with other amino acids. Therefore, analyses of dhal samples of ten cultivars were carried out in an amino acid analyzer after alkaline hydrolysis and were compared with the results obtained from the colorimetric procedures of Concon (1975) and Spies and Chambers (19 49). Tryptophan values obtained using the amino acid analyzer ranged from 0.47 to 0.63 when expressed as percent of protein and the mean value was 0.53%. When expressed as a chemical score, the values ranged from 47 to 63. The mean values obtained by the two colorimetric procedures were about 30% higher, and further work is in progress to determine a suitable methodology.

Pigeonpea also provides several other essential nutrients like carbohydrates, and the chemical composition of some commonly utilized pigeonpea cultivars are shown in Table 3. The protein percent in dhal samples ranged from 21.4 to 25.4% while the starch content ranged from 52.5 to 59.9%. It is important to ensure that the advanced lines of pigeonpea bred for higher yields and better nutritional quality do not suffer a reduction in the concentration of essential minerals and vitamins.

Antinutritional Factors

Of the several antinutritional factors that are reported to be present in legumes, the trypsin and chymotrypsin inhibitors have been studied in detail (Liener 1979). Although pigeonpea has lower levels of trypsin and chymotrypsin inhibitor activities as compared with soybeans, some of the wild relatives of pigeonpea have been found to contain higher concentrations of these inhibitors (Table 4). The highest trypsin and chymotrypsin inhibitor activities were observed in *Rhynchosia rothii,* and this species also showed the lowest value for in vitro protein digestibility. Some of the antinutritional constituents are destroyed on cooking, but this has not been tested in the case of wild species of pigeonpea. However, the presence of some of these inhibitors may have a role in insect or disease resistance characteristics.

There is little available information on the presence or absence of other undesirable components in pigeonpea, such as oligosaccharides, which are reported to cause flatulence, lectins, and goiterogens, and there is a need to carry out more investigations in this

Table 3. Chemical composition of dhal samples of soma pigeonpea cultivars.[a]

Cultivar	Protein (%)	Starch (%)	Soluble sugars (%)	Fat (%)	Crude fiber (%)	Ash (%)
HY-3C	21.5	57.2	4.9	2.0	1.0	3.1
ICP-1	23.0	56.9	4.5	1.1	1.1	3.7
ST-1	21.4	57.3	4.8	1.3	1.0	3.4
No. 148	22.8	58.9	5.3	13	1.1	3.6
T-7	24.2	59.9	5.1	1.3	1.1	3.5
T-17	25.4	53.6	4.4	1.6	1.1	3.8
T-21	22.9	55.0	4.9	1.4	1.0	3.7
BDN-1	22.4	56.2	5.0	1.7	0.9	3.6
C-11	22.7	57.8	4.8	14	1.1	3.9
Gwalior-3	24.8	52.5	4.7	1.4	1.1	4.0

a. As is basis.

Table 4. Protein content, level of trypsin and chymotrypsin Inhibitors, and protein digestibility in cultivars of plgeonpea and its wild relatives.

Species	No. of samples (dhal)	Protein (Nx6.25) (%)	Trypsin inhibition		Chymotrypsin inhibition		In vitro protein digestibility (%)
			Units/mg meal	Units/mg protein*	Units/mg meal	Units/mg protein[a]	
Cajanus cajan							
Mean	3	24.6	13.5	69.4	4.2	22.1	60.5
Range		23.1-26.2	12.5-15.1	67.1-71.3	3.5-5.0	15.3-27.8	57.9-64.1
Wild species							
Atylosia spp							
Mean	6	28.4	17.6	76.0	14.2	61.8	61.1
Range		27.1-29.3	13.3-25.8	54.5-121.4	5.9-22.0	24.2-92.4	52.6-68.1
Rhynchosia spp	1	27.6	82.4	445.7	20.9	113.2	40.9

a. Based on the amount of protein extracted.

Table 5. The distribution of polyphenolic compounds in the seed components of plgaonpaa cultivars.

Cultivar	Testa color	Seed coat (%w/w)	polyphenols (mg/g sample)		
			Seed coat	Dhal	Whole seed
BDN-1	Dark red	15.2	106.9	1.9	15.1
C-11	Light red	15.7	92.3	1.7	14.2
NP (WR)-15	White	16.4	37.2	1.4	6.0
HY-3C	White	13.0	27.0	1.6	3.7

area. Similarly, the digestibility of starch and protein in pigeonpea and their role in human nutrition needs careful evaluation.

The role of polyphenolic compounds (loosely termed as tannins) in the bioavailability of nutrients of pigeonpea needs to be investigated. This is particularly important in those areas where pigeonpea is consumed as whole green peas. Analysis of four pigeonpea cultivars with different seed-coat colors showed that the seed coat contained the highest proportion of polyphenols and red seed appears to have a higher concentration of polyphenols than white (Table 5). Preliminary in vitro studies indicated that the polyphenolic compounds may affect some of the digestive enzymes. This again needs a more detailed examination.

Cooking Quality and Consumer Acceptability

Consumers are the end users of pigeonpea, and cooking quality and consumer acceptability are two aspects of vital importance to any crop improvement program.

Cooking Quality

The cooking time of 25 pigeonpea dhal samples showed a variation from 24 to 68 minutes. The dhal samples were analyzed for various physicochemical characteristics and the ranges and means of these values are shown in Table6. Negative and highly significant correlation coefficients were obtained between the cooking

Table 6. Relationship between tha physicochamical characterlstics and cooking time in 25 cultivars of pigeonpea.

Constituent	Range	Mean	Correlation coefficient(r) with cooking time
Cooking time (min)	24-68	38	
Seed weight (g/100 seeds)	6.2-20.7	9.6	-0.434*
Solids dispersed (%)[a]	20.8-54.7	37.4	-0.813*
Water absorption			
(g/g dhal)[a]	1.69-2.65	2.25	-0.807**
(g/g whole grain)[a]	0.63-1.34	1.02	-0.695**
Increase in volume			
(v/v dhal)[a]	1.18-1.86	1.51	-0.052
(v/v whole grain)[a]	0.91-1.54	1.13	+0.163
Gelatinization temp of starch (°C)	73-81	76	-0.267
Water-soluble amylose (%)	7.3-12.0	9.8	+0.042
Total amylose (%)	19.2-24.0	21.8	-0.049
Starch (%)	51.5-63.4	58.6	+0.216
Soluble sugars (%)	3.6-5.3	4.8	+ 0.178
Protein (%)	19.7-25.2	22.1	+0.388*
Nitrogen solubility index (%)	28.7-42.5	36.4	-0.634**
Nitrogen content in solids dispersed (%)	19.6-31.8	27.3	-0.756**

* Significant at 5% level.
** Significant at 1% level.
a. Boiled at 100°C for 25 m in.

time and solids dispersed, water-absorption characteristics of dhal or whole grain, nitrogen solubility index, and nitrogen content in dispersed solids. Further work is being carried out with more samples. There is still a need to develop a suitable method to objectively test the cooking time of pigeonpea.

Consumer Acceptability

Most of the pigeonpeas that are grown in India are first processed and only the dhal samples enter the market channels for consumer use. Therefore for pigeonpea utilization, milling and processing characteristics of whole seed, as well as the consumer's preferences, are important

A survey was carried out in the three states of India — Madhya Pradesh, Uttar Pradesh, and Maharashtra — that account for more than 75% of the total production of pigeonpea in India. Several dhal mill owners were interviewed, and their opinions and impressions regarding the milling characteristics of various types of pigeonpea were obtained. Several villagers were interviewed in areas where pigeonpea processing is done at home with a stone grinder. In addition, consumers' preferences for dhal material were obtained. Only the important findings are listed here. When a mechanical mill is used for the dehulling process, white pigeonpea seed is reported to give higher dhal yields. Light red or red seed is also preferred because of the uniformity of seed size and shape. Although the dhal yield is reported to vary from one mill to another, depending on the processing method used, important criteria in general are seed size, shape, and hardness; round seed of medium size, with greater hardness, has been reported to give better recoveries of dhal. Village-level home processing appeared to give lower dhal recoveries (about 62% as compared to 71% obtained in a mechanically operated mill). This again is subject to variation, depending on the processing techniques used.

Consumers seem to prefer the local varieties grown in their own fields. There is a wide variation in the preferences for color because of long-term associations with a particular color in a particular village. The choice of color varies from black to red to white. However, interestingly, taste seems to have a higher priority than cooking time, and more data need to be obtained to verify this observation.

The results of this survey have given us some ideas about the preferences of consumers and mill owners. It would be helpful to gather additional data to obtain a better understanding of the needs of the consumers. There is a need to carry out a survey in other countries where green pigeonpeas are consumed.

References

CONCON, J. M. 1975. A rapid and simple method for the determination of tryptophan in cereal grains. Analytical Biochemistry 67: 206-219.

EVANS, I. M., and BOULTER, D. 1975. S-methyl-L-cystine content of various legume meals. Qualitas Plantarum—Plant Foods for Human Nutrition 24: 257-261.

LIENER, I. E. 1979. Protease inhibitors and lectins. Pages 97-122 in Biochemistry of nutrition, Vol. 27, (eds. A. Neuberger and T. H. Jukes). Baltimore: University Park Press.

REDDY, L.J., GREEN, J. M., SINGH, U., BISEN, S. S., and JAMBUNATHAN, R. 1979. Seed protein studies on *Cajanus cajan, Atylosia* spp., and some hybrid derivatives. Pages 105-117 *in* Proceedings, Symposium on Seed Protein Improvement in Cereals and Grain Legumes, Vol. II. IAEA, FAO, and GSF, Neuherberg, Federal Republic of Germany.

SINGH, U., and JAMBUNATHAN, R. 1981. Methods forthe estimation of protein in pigeonpea *(Cajanus cajan* [L.] Millsp.) and the relationship between whole grain and dhal protein contents. Journal of the Science of Food and Agriculture. (in press.)

SPIES, J. R., and CHAMBERS, D. C. 1949. Chemical determination of tryptophan in proteins. Analytical Chemistry 21: 1249-1266.

The Role of Pigeonpeas in Village Diets

Patricia Day Bidinger and Bhavani Nag*

Abstract

The role of pigeonpeas in the six villages that comprise ICRISA T's Village-Level Studies is examined in the context of the three agroclimatic zones they represent and of the production and consumption by 40 families in each village. The families represent landless laborers (ten households) and small, medium, and large farm families (ten each). Agronomic and economic data were collected by resident investigators and 24-hour dietary recalls were taken by home scientists at four intervals spanning more than a year.

The average production of pigeonpea in kg/family is presented against a background of village characteristics including cropping pattern, soil type, and rainfall. Other data include consumption of pigeonpea by both age group and farm-size category, pigeonpea consumption as a percentage of total pulses consumed, pulse intake relative to cereal intake, and the nutritive contribution of pigeonpea to village diets.

From early times man has believed pulses to be a necessary component of his diet. References to benefits of pulses are found in the Bible in the book of Daniel. Nutritionists and others concerned with food production and consumption have long advised the inclusion in the diet of both cereals and pulses due to their complementary nature. Little is known, however, about production and consumption by individual farm families in rural pulse-growing areas. This paper will discuss the ecology of one pulse, pigeonpea, in villages that are part of ICRISAT's Village-Level Studies.

One of the key objectives of the Economics Program at ICRISAT is to identify socioeconomic and other constraints to agricultural development and to evaluate alternative means of alleviating them through technological and institutional change. Accordingly, in 1975, members of the Economics Program established a series of Village-Level Studies (VLS) in six villages covering three major agroclimatic zones in two states of India: Maharashtra and Andhra Pradesh. A map of India (Figure 1) illustrates not only the boundary of the semiarid tropics (SAT), but the agroclimatic zones used for village selection. Two villages in Maharashtra's Akola District, Kanzara and Kinkheda, representa relatively assured rainfall area with medium-deep Vertisols (black soils). Rainfall averages 820 mm yearly. Both rainy season (*kharif*) and postrainy season *(rabi)* cropping are practiced. In Sholapur District, also in Maharashtra, Shirapur and Kalman villages typify the nonassured zone characterized by an annual average rainfall of 690 mm received in a bimodal pattern. The deep to medium-deep Vertisols are often left fallow during the rainy season due to the riskiness of planting when the rains are not dependable. The third area selected as representative of the Indian SAT is Mahbubnagar District in Andhra Pradesh with an annual rainfall of 710 mm. Dokur and Aurepalle villages represent this area, which is characterized by shallow to medium-deep Alfisols (red soils). Irrigation, based on tanks that collect runoff water during the rainy season and wells, distinguish the district from the other two.

Cropping patterns differ in the three zones as illustrated in Table 1. The Akola District villages of Kanzara and Kinkheda have similar patterns; cotton, sorghum, groundnut, and pigeonpea are grown during the rainy season, while wheat and chickpea are planted as postrainy season crops. What little irrigation is available is used

* Economics Program, ICRISAT.

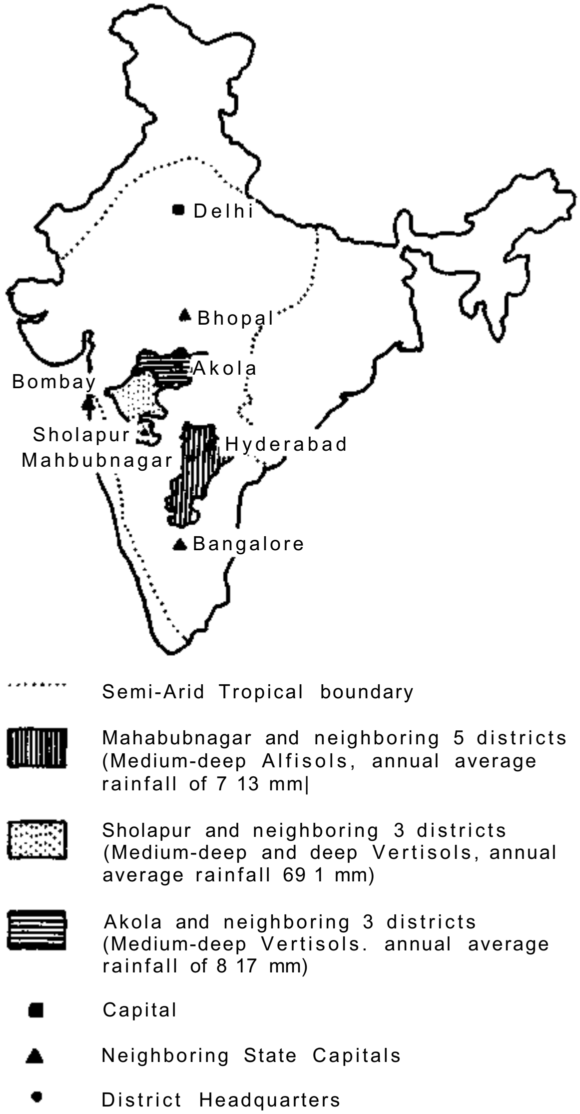

Figure 1. Agroclimatic zones used for village selection.

on wheat. In Shirapur and Kalman in Sholapur District, pigeonpea, pearl millet, and the fiber crop "rala" are the rainy season crops; sorghum and pulses are grown during the postrainy season. Sugarcane is grown during both seasons and it is all irrigated. Aurepalle and Dokur in Mahbubnagar District have different cropping patterns as a result of differences in the amount of irrigation available. In Aurepalle, castor, sorghum, paddy, and pulses are rainy season crops; paddy and chillies are grown in the postrainy season. In Dokur, with its substantially larger amount of irrigation (32%), paddy and groundnut are grown in both the seasons.

The majority of village residents are either laborers or cultivators, with the latter accounting for 50% to 70% of the total (Table 2). A stratified random sample of 40 families was chosen in each village to represent landless laborers, small, medium, and large farmers (ten from each group). The operational land-size categories used to classify the farm holdings in each village are different for each village due to different man: land ratios and land productivity and wide variation in average size of landholdings (Table 3).

The ICRISAT Village-Level Studies (VLS) were initiated using a multidisciplinary approach as a way of gathering microlevel data. A resident agricultural economist was placed in each village to monitor traditional farming practices and to collect data on income, assets, labor utilization, and cropping patterns, as well as a wide variety of related aspects. In late 1976, a nutrition and health component was added to the Village-Level Studies, in collaboration with the National Institute of Nutrition and the Andhra Pradesh Agricultural University Home Science College, with the aim of determining the availability of nutrients and comparing them with recommended allowances. Data on seasonal distribution of nutrients, seasonal health status, socioeconomic status, labor utilization, and farming systems for the sample households were gathered. Two teams, each consisting of a nutritionist and a physician, obtained information on food consumption and health status. From late 1976 to early 1978, four 24-hour dietary recalls were obtained for each family. Information consisted of the amount and type of foods consumed and their preparation. A questionnaire was administered to explore topics relating to food beliefs and practices.

Samples of the major household cereal and pulses were obtained for protein determination. Actual sampling permitted ICRISAT researchers to determine variability in home-stored samples, as well as to make a more accurate assessment of respondents' actual nutritional intakes. As a result of ICRISAT's Village-Level Studies much has been learned about the role of pigeonpea in the village. The following discussion will cover (a) general agronomic practices, (b) types of food preparation, (c) consumption patterns, and (d) the nutritive contribution of pigeonpea to village diets.

Table 1. Characteristics of selected villages in ICRISAT's Village-Level Studies.

District:	Akola		Sholapur		Mahbubnagar	
Village:	Kanzara	Kinkheda	Shirapur	Kalman	Dokur	Aurepalle
Major crops	Cotton Sorghum Pigeonpea Groundnut Wheat	Cotton Sorghum Pigeonpea Groundnut Wheat	Sorghum Pearl millet Chickpea Pigeonpea Groundnut	Sorghum Pearl millet Chickpea Pigeonpea Groundnut	Rice Sorghum Groundnut Pigeonpea Pearl millet	Rice Sorghum Castor Pearl millet Pigeonpea
Soil types	Medium-deep Vertisols		Deep and medium-deep Vertisols		Shallow and medium Alfisols	
Rainfall (annual average at taluka headquarters. mm.)	820	820	640	660	760	860
Irrigated area as % of total cropped area*	4.5	0.9	8.2	9.2	32.3	12.0

a. Sources of irrigation are wells In the Maharashtra villages and tanks and wells in the Mahbubnagar villages.

Table 2. Composition of village households.

District:	Akola		Sholapur		Mahbubnagar	
Village:	Kanzara	Kinkheda	Shirapur	Kalman	Dokur	Aurepalle
Occupation						
Laborers	54' (32.0)[b]	55 (38.5)	97 (32.7)	156 (36.9)	76 (24.3)	146 (30.7)
Cultivators	109 (64.5)	83 (58.0)	183 (61.6)	211 (49.9)	226 (72.2)	322 (67.7)
Others	6 (3.5)	5 (3.5)	17 (5.7)	56 (13.2)	11 (3.5)	8 (1.6)
Total	169 (100)	143 (100)	297 (100)	423 (100)	313 (100)	476 (100)

Source: VLS Studies Census, May 1975.
a. Number of households In eech occupational class.
b. Figures in parentheses Indicate % of households in occupatlonal class.

Agronomic Practices

With the exception of Dokur in Andhra Pradesh, the majority of farmers in all villages grow pigeonpea (Table 4). Of the approximately 30 farmer respondents in each village, Shirapur, in Maharashtra, had the fewest farmers growing pigeonpea (50%) while Kalman, in the same district, and Kanzara, in Akola District, had the most with 83% and 85% respectively. More medium and large farmers grew pigeonpea, with the exception of Shirapur, where more small farmers than medium farmers grew the crop. In the three other Maharashtra villages 80 to 100% of all medium and large farmers grew pigeonpea while only 50 to 67% of the small

Table 3. Operational size[a] categories used to classify farm holdings In the six selected villages.

Village	Small (ha)	Medium (ha)	Large (ha)
Aurepalle	0.20-1.21	1.22-3.24	>3.24
Dokur	0.20-0.89	0.90-2.11	>2.11
Shirapur	0.20-2.02	2.03-5.26	>5.26
Kalman	0.20-3.64	3.65-8.50	>8.50
Kanzara	0.20-1.82	1.83-5.26	>5.26
Kinkheda	0.20-2.02	2.03-4.45	>4.45

Source: Jodha et al.1977.

a. Operational size was defined as the area of owned land, minus the area leased or sharefarmed to someone else. plus the area leased or sharefarmed from someone else.

Table 4. Percentage of farmers planting pigeonpea in six villages of SAT India.

Aurepalle, Andhra Pradesh	69
Dokur, Andhra Pradesh	3
Shirapur, Maharashtra	50
Kalman, Maharashtra	83
Kanzara, Maharashtra	85
Kinkheda, Maharashtra	73

Table 5. Average dates of sowing and harvesting of pigeonpea in ICRISAT's Village-Level Studies.

Village	Sowing	Harvesting
Aurepalle	June	September-October
Shirapur	End of June, July	October
Kalman	End of June, July	October
Kanzara	Mid to end June	Mid-January
Kinkheda	Mid to end June	Mid-January

farmers did so. In Aurepalle, A.P., 100% of the medium farmers and 70% of the large farmers grew pigeonpea.

In all villages, sowing of pigeonpea is done during the rainy season from early June to late July (Table 5). Harvesting ranges from September in Aurepalle to mid-January in Kanzara and Kinkheda.

In the ICRISAT study villages pigeonpea is generally intercropped in various combination rows (Table 6). Common combinations are sorghum/pigeonpea, cotton/pigeonpea or a combination of the three. In Aurepalle, either sorghum or the cash crop castor is commonly grown with pigeonpea on the village's red soils. In the Maharastra villages pigeonpea is planted with a wider variety of crops, although most commonly it is intercropped with cotton and/or sorghum in the Akola villages and pearl millet or fiber crops such as "rala" in the Sholapur villages.

Table 6. Common pigeonpea Intercropping combinations.

Village	Intercrop	Row Ratio
Aurepalle	Pigeonpea/sorghum	1:6-1:12
	Pigeonpea/castor	1:5-1:8
Shirapur[a]	Pigeonpea/fiber crops	10:2
Kalman[a]	Pigeonpea/pearl millet	6:2-8:2
Kanzara	Pigeonpea/sorghum, cotton	2:2:12-2:2:16
Kinkheda	Pigeonpea/cotton	2:6-2:15

Source: ICRISAT economic investigators, VLS data schedules.

a. Pigeonpea is most often grown as a sole crop.

Pigeonpea is grown as a sole crop only in the Sholapur villages, Shirapur and Kalman, and yields are very low. The 2-year average (1975-77) for Shirapur was reported as 120 kg/ha and for Kalman 22.5 kg/ha. Part of the poor yield may be due to the failure to spray the crop against insects or to consider the yield of green pigeonpea taken for home consumption before harvest. There is still no doubt that yields are low.

Comprehensive yield data are not available, as yield determination of an intercrop is extremely difficult; however, the production of pigeonpea per family for the period of the diet survey is available (Table 7). This is probably more relevant than yield, as it demonstrates what is actually available for consumption. Per family production increased linearly with farm size for all but Kinkheda. As little as 18 kg were harvested among small farmers in Aurepalle, to a high of 263 kg harvested by large farmers in Kanzara. Greater production is due to greater area under cultivation ratherthan to greater per hectare yield.

Table 7. Production of pigeonpea by farm aiza.

Village	Farm size			
	Small	Medium	Large	Average
Aurepalle	18[a]	25	49	32
Shirapur	100	123	238	178
Kalman	95	147	175	147
Kanzara	39	98	263	154
Kinkheda	127	119	251	175

a. Total production In kg per family from Sept 1976 to Feb 1978.

Table 8. Percent of protein supplied by pulses as a percent of all food grains consumed.

Year	Protein (%)
1951-55	32
1961-65	29
1971-73	22

Source: Diet Atlas of India, Indian Council of Medical Research, 1974.

Pigeonpea Preparation

Three major dishes are prepared using pigeonpea as a principal component: *dhal, sambar,* and *khichri.* Dhal and khichri are eaten throughout India while sambar is a traditional south Indian dish. All three preparations may be made using pigeonpea as well as other pulses, depending upon the preference and economic status of the family. For example, mung dhal is preferred by south Indians when making khichri; pigeonpea is preferred by north Indians.

There are as many ways to make dhal and sambar as there are spices in India. In general, the following methods are employed to make each dish. The initial step for all preparations is the removal of the seed coat and the splitting of the cotyledons. To do this, pigeonpeas are soaked in water then sun-dried. After drying they are either ground in a *chakki* or pounded. To prepare dhal, the desired quantity of pigeonpea dhal is placed in hot water and boiled until tender. Seasonings are fried in a small quantity of oil before being added to the cooked, and sometimes mashed, pigeonpea. The seasonings consist of a variety of the following depending upon the season and economic status of each cook: onions, green or red chillies, mustard seeds, curry leaves, tomatoes, or other vegetables. Salt is added to taste.

Sambar is a dhal-like preparation in that it contains a pulse and a multitude of spices. It differs in the ratio of water to pulses, with considerably more water added to sambar. Vegetables are always added later or at the same time, depending upon the time needed to cook them. The spices, which consist of roasted and powdered cumin seed, coriander seed, and fenugreek, *are* added *after* the dhal and vegetables are cooked. At the same time, chilli powder, turmeric, tamarind pulp, curry leaves, and salt are added. The preparation is then seasoned with red chillies and mustard seeds which have been fried in oil.

Khichri, the third preparation, is made with pigeonpea and rice in a V. 2 or 2:1 ratio. Often, onions and green chillies are fried in oil before being added to the washed rice and pigeonpea dhal. They are cooked with sufficient water until both *are* tender *and* all the water absorbed. The dish is then seasoned with salt.

Consumption

Historically, pulses have been considered a major source of dietary protein. In India the dietary protein supplied by them has steadily decreased from 1951-55 when pulses accounted for 32% of the total protein supplied by all food grains (Table 8). By 1961-65 the percent of protein from pulses had dropped to 29% and by 1971-75 to 22%. In the six study villages the percent protein supplied by pulses for the 1976-78 period was 11% (range 6-18%).

The major reason forthis decrease is the crop itself. The instability of yield makes pulses a far riskier crop to grow than cereals. Although pulses are desired by nearly all Indians, their high cash value and low yield accounts for generally reduced consumption.

Data for the following tables *are* derived from the VLS diet survey. The consumption pattern of pigeonpea differs widely by age group, farm size, and village (Table 9). Consumption is nearly linear, with small farmers consuming the

Table 9. Consumption (g) of pigeonpea by aga group and landholding class.

Village	Landless	Small	Medium	Large
Aurepalle				
1-6	1 (3)	3 (6)	3 (6)	11 (13)
7-18	0	4 (6)	6 (9)	17 (27)
Above 18	0	4 (6)	4(11)	22 (36)
Dokur				
1-6	21 (26)	2 (5)	1 (3)	11(14)
7-18	9(18)	6(10)	2 (4)	19(19)
Above 18	9(25)	5(11)	6(24)	18 (23)
Shirapur/Kalman				
1-6	7 (6)	15(16)	12(14)	11 (12)
7-18	14(15)	14(12)	14(14)	23 (26)
Above 18	15 (20)	15(14)	17(19)	22 (24)
Kanzara/Kinkheda				
1-6	11 (12)	16 (14)	20 (20)	16(17)
7-18	18(17)	26 (24)	30(21)	28 (19)

a. Standard deviation.
N =~925 per village.

least amount and large farmers the most. The amounts range from zero among landless laborers and their children aged 7 through 18 years from Aurepalle to 32 g/day among Kanzara and Kinkheda adults from medium and large farm households. In Dokur, where families must purchase their pulses, consumption is not appreciably different from that of the Aurepalle families. Using a mean family size of six persons, adult consumption data and the production figures from Table 7, calculations may be made that demonstrate production covers consumption for all groups except large farmers in Aurepalle and small farmers in Kanzara. The amount remaining for sale varies from an average of 5.5 kg for small farmers in Aurepalle to 170 kg in large farm households in Shirapur. It must be remembered, however, that these calculations are based on averages only and may not reflect the actual picture for individual households.

The preference for pigeonpea over the many other pulses grown in India is reflected in Table 10. Pigeonpea consumption as a percent of total pulse consumption is highest in Dokur where almost all pulses are purchased. It is evident that pigeonpeas are a preferred pulse when one considers that half or more of all pulses consumed were pigeonpea.

Table 10. Pigeonpea consumption as a percent of total pulse consumption.

Village	Age Group		
	1 to 6	7 to 18	Adults
Aurepalle	44	48	59
Dokur	85	70	71
Shirapur	62	61	57
Kalman	72	66	64
Kanzara	43	52	48
Kinkheda	63	59	48

Relative to cereals pulse consumption is low, as shown in Table 11. Where pulse production is greatest, as in the four Maharashtra villages of Shirapur, Kalman, Kanzara, and Kinkheda, the ratio of cereals to pulses decreases markedly, thus reflecting the increase in pulse intake. These ratios are in excess of those recommended by the National Institute of Nutrition in India, which encourages a cereal: pulse ratio of 3:1 for very young children, 5:1 for women, and 6:1 for men. Although these desired ratios are not found, the tendency to feed young children more pulses (relative to cereals) is found in each of the six study villages.

Table 11. Relative cereal and pulse consumption (g cereal : g pulses) by village and age group.

Village	Age group		
	1 to 6	7 to 18	Adults
Aurepalle	31:1	35:1	37:1
Dokur	23:1	31:1	42:1
Shirapur	15:1	14:1	17:1
Kalman	14:1	18:1	20:1
Kanzara	7:1	9:1	10:1
Kinkheda	9:1	10:1	10:1

Food Beliefs

Another factor influencing pigeonpea consumption (and pulses in general) is the food beliefs attached to it. Although it is an important factor it is not possible to quantify its effect on consumption patterns because we do not know how often pigeonpea is actually avoided. Responses are conflicting, with some declaring pigeonpea a food to be avoided during pregnancy, lactation, and certain illness (a "hot" food) and others stating that pigeonpea is to be avoided during the colder months of the year and during illnesses which cause fever and the common cold (a "cold" food). From 5 to 14% of the respondent households listed pulses as possessing "hot" or "cold" properties. This would indicate that pulses do not have a clearly defined role as a "hot" or "cold" food. In two villages pigeonpea was named specifically as a "hot" food. In Aurepalle, A.P., 13.3% of the respondents said pulses were a "hot" food, and of these, 65% specifically named pigeonpea. Similar results were obtained for Shirapur, Maharashtra.

Nutritive Value of Pigeonpea

The percent of protein, energy, and lysine supplied by pigeonpea in respondent diets is presented in Table 12. Less than 10% of the protein and 5% of the energy of VLS diets came from pigeonpea. The maximum lysine provided was 21.7%. The fact that these figures are low reflects the low consumption of pigeonpea. The figures remain low even when pulse consumption is aggregated. There is also little seasonal variation in pulse consumption.

Table 12. Mean percentage of selected nutrients provided by plgeonpeas.

	Protein	Energy	Lysine
Aurepalle			
Mean (%)	3.4	4.8	6.2
Range	(0.8-7.0)	(0.3-2.4)	(1.6-13.1)
Dokur			
Mean (%)	5.6	2.0	10.1
Range	(3.7-9.2)	(1.3-3.3)	(6.3-16.4)
Shirapur			
Mean (%)	5.4	2.5	11.9
Range	(2.5-8.2)	(1.3-4.0)	(4.7-19.0)
Kalman			
Mean (%)	6.8	3.2	16.5
Range	(3.5-9.2)	(1.6-4.2)	(9.6-22.3)
Kanzara			
Mean %)	6.9	3.1	16.6
Range	(5.1-8.0)	(2.2-3.6)	(12.8-18.7)
Kinkheda			
Mean (%)	9.7	4.5	21.7
Range	(3.3-13.0)	(1.4-6.1)	(8.6-27.8)

N = ~925 in each village.

Summary and Conclusion

The consumption of pigeonpeas follows a linear trend, with landless labor households consuming the least and large farm households the most. Overall, the consumption of this pulse is low, although it is preferred over other pulses by the majority of households. Pulse consumption relative to cereal consumption is highly variable with lower cereal: pulse ratios found in villages with higher pulse production. Even with the low consumption pigeonpea contributes as much as 22% of the total lysine and 10% of the total protein in respondents' diets.

It is hypothesized that low yields and a high market price account for much of the low consumption.

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References

ICMR (Indian Council of Medical Research). 1974. Diet atlas of India. Hyderabad, India: ICMR, National Institute of Nutrition.

JODHA, N. S., ASOKAN, M., and RYAN, JAMES G. 1977. Village study methodology and resource endowments of the selected villages in ICRISAT's Village-Level Studies. ICRISAT Economics Program occasional paper 16, Patancheru, A.P., India.

Alternative Uses for Pigeonpea

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Abstract

This paper reviews the utilization of Cajanus cajan *as a green manure crop and in animal feeding as forage crop, crop residues, seed, or dhal mill by-products.*

High total dry-matter yields of up to 57 000 kg/ha per year have been recorded, but yields of edible forage would be approximately 50% of this to allow for stem. High levels of beef production of up to 1.25 kglhead per day and 1120 kglha per year have been recorded in Hawaii. High liveweight gains appear to be related to the availability of seed on the plant, but animal production on green forage alone may be limited. Further research is required to define intake, digestibility, and animal production on pigeonpea forage.

In evaluation of harvest residues, pigeonpea pods were shown to have a low nutritive value but can be fed with a good quality grass hay. Harvest trash that contains leaf, stem, and pod also had low intake and digestibility values. Nutritive value may also be limited by low sulfur contents and high N:S ratios.

The limited data available on feeding seed to poultry and pigs suggest that pigeonpea seed meal is a satisfactory protein supplement, up to 30% of the ration. Studies with pigeonpea seed meal in commercial pig rations are required. Research on fractionating dhal mill by-products into fine powder fraction and broken seed for nonruminant feeding and seed husk for ruminants is suggested.

The title "alternative uses" suggests growing pigeonpea for purposes other than seed production. While this may occur in some cases such as when grown purely for forage or green-manure cropping, more usually we are concerned with the utilization of crop stubble after harvest, and residue after threshing, seed cleaning, or dhal-making. This review will concentrate mainly on the use of *Cajanus cajan* in animal feeding. Other uses of *Cajanus cajan* in human nutrition, folk medicine, and minor uses are well reviewed by Morton (1976).

Use as a Green Manure Crop

The role of a leguminous green-manure crop is basically to provide for the incorporation of nitrogen-rich organic matter, which also provides ground cover and protection, and improves soil structure. Pigeonpea has been used in this role in sugarcane (Krauss 1932), banana land (Wills and Berrill 1953), pineapple plantations (Mitchell 1953; Krauss 1932), and in crop rotations in Brazil (Neme 1955; Mello and Brasil 1960). Gooding (1962) reports data from S. Rhodesia (Zimbabwe) where a green-manure crop of *C. cajan* gave significantly higher yields of a following crop of maize than the grass forage crops *Sorghum sudanense* and *Pennisetum typhoides,* but not as high as a green manure of velvet beans *(Stizolobium deeringianum).*

For a major effect in green manuring, *Cajanus* should be planted at high density and incorporated before too much woody tissue has developed, even though maximum levels of dry-matter yield, nitrogen, and other mineral contents are attained at the stage between flowering and seed set (Mehta and Khatri 1962). Optimum time for incorporation will depend on variety and date of sowing because of photoperiod responses, but for most varieties this would be prior to or aboutflowering. At 85 days from planting Garcia (1980) reported a nitrogen

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yield in tops of 220 kg N/ha for Code 1 variety at the flowering stage in Trinidad. At 55 days nitrogen yield in tops was only 10 kg N/ha, demonstrating that plowing in at an easily managed early stage may limit the input of nitrogen, and that some compromise will have to be made between nitrogen yield and plant maturity. However, Krauss (1932) states that even mature woody crops can be readily plowed under with a large tractor and heavy discs.

Green-manure crops have declined in use, as land is tied up in relatively unproductive use during the growth of the crop. However, with the increasing cost of fertilizer nitrogen, some return to green-manure cropping may occur. In any case, growing *Cajanus* purely for green manure would seem to be wasteful, since the same end of raising soil nitrogen and organic matter could be achieved by grazing the crop in situ and allowing the return of faeces and urine.

Use as a Forage Crop

Cajanus as a forage crop may be grown in pure stands and either grazed or cut for hand-feeding, or grown as the legume component in a mixture with grass.

Dry-Matter Yields

Pure Stands, Cut

The yield of forage obviously depends on the growing conditions and soil fertility, and also on the variety, cutting frequency, and height of cutting. These latter factors also affect mortality in the stand. Thus yields vary widely (Table 1).

Norman et al. (1980) evaluated pigeonpea as an annual legume forage for autumn use in coastal New South Wales, Australia. This is a relatively high latitude (34°S) for pigeonpea, and growth during winter is limited by low temperatures — minimum temperatures down to 5°C — and killing frosts. Norman et al. (1980) obtained a maximum accumulated yield of 13 540 kg/ha from an October sowing harvested at the end of April, but leaf yields were similar, whether the crop was sown in October or November. Defoliation during the growing

Table 1. Dry-matter yields of *C. cajan* subjected to a range of cutting treatments at different locations.

Management	DM Yield (kg/ha)	Location	Reference
Single cut at (days)			
55	210		
85	1 320		
105	2 200	Trinidad	Garcia (1980)
125	2 940		
105	8 000	S. E. Queensland	Rowden et al. (1980)
154	7960	Florida, U.S.A.	Killinger (1968)
195	13 540	Central coastal N.S.W.	Norman et al. (1980)
210	6 180	S. E. Queensland	Akinola et al. (1975)
220	30 240	Kimberley, W.A.	Parbery (1967)
2 (at 220 and 352 days)	51 000	Kimberley, W.A.	Parbery (1967)
2	57 600	Colombia	Herera et al. (1966)
3	15800	Florida	Oakes and Skov (1962)
3	12 200		
4	11 100	Queensland	Akinola and Whiteman (1975)
6	9 300		
12	7 100		
2 (63 and 168 days)	4 750		
2 (84 and 168 days)	3 790		
2 (105 and 168 days)	3 560	Central coastal N.S.W.	Norman et al. (1980)
2 (126 and 168 days)	5 570		
2 (146 and 168 days)	6 250		
1 (168 days)	7 230		

season reduced total production, due to slow regrowth and plant mortality. They concluded that pigeonpea could make a useful contribution to dairy forage if planted up to early November and grazed or cut for forage overthe period March to May.

In lower latitude environments with year-round growing seasons or with irrigation, such as at Kimberley in Western Australia (Parbery 1967) and in Colombia (Herrera 1968) very high yields were obtained. These yields are the highest recorded for a forage legume, higher than those of *Leucaena leucocephala* (Anonymous 1977), and equivalent to high-yielding tropical grasses fertilized with adequate nitrogen. However, actual yields of edible forage must be discounted for stem content, which can be over 50%.

With repeated defoliations, forage yields increase as intervals between harvests increase, but the percentage stem also increases, so that yield of total digestible nutrients may not change as much. Akinola and Whiteman (1975) found that percentage stem increased from 34% at 4-week cutting intervals and 43% at 8 and 12 weeks, to 51% at 16 weeks. They suggested the optimum defoliation intensity was between 8 to 12 weeks. Similarly, Garcia (1980) found that stem percentage increased from 17% at 55 days to 38% at 85 days, and 41% at 105 and 125 days, so that crop maturity in a single cut also affects the yield of digestible nutrients. The yields of edible forage harvested under regular defoliation were similar to those from other shrub legumes such as *Leucaena leucocephala* (Akinola et al. 1973), but *C. cajan* is shorter lived. Akinola and Whiteman (1975) recorded 13 to 59% mortalities of plants under regular defoliation (after 72 weeks of harvesting) depending on variety and cutting treatment.

Pure Stands, Grazed

There are two main methods by which *Cajanus* is utilized under grazing: regular grazing of the vegetative growth (at intervals) or using the crops as a "standover" forage for the dry season. In this latter use the crop provides leaf, seed, and pod to the animal during a period usually marked by deficits of energy and protein.

There are few precise data on yields, stocking rates, and animal production from *C. cajan* forage. Krauss (1932) reported the wide-scale use of pigeonpea pastures in Hawaii in the 1920s, where over 1600 ha were grown mainly for beef fattening. Carrying capacities of good stands of pigeonpea varied from 1.2 to 3.7 head/ha, with average stocking rates of 25 animals/ha per year. Average daily gains from 0.7 to 1.25 kglhead per day were recorded. Authentic records showed production of liveweight in excess of 1120 kg/ha per year. These are the second highest levels of beef production recorded on tropical legume pastures. The highest value of 1304 kg/ha per year was also reported from Hawaii by Younge and Plucknett (1963) on a mixed pasture of *Digitaria decumbens* and *Desmodium intortum.* The high levels of gain per head per day indicate the high nutritive value of pigeonpea, while the high production per hectare demonstrates the potential for dry-matter production of this legume underthe excellent growing conditions in Hawaii. Further evidence *of* the high nutritional value of *C. cajan* is provided by Henke (1943) in feeding trials with dairy cattle, discussed later in this paper.

Utilization of *C. cajan* as a standover forage in the dry season for beef cattle has been studied in a number of countries.

Henke et al. (1940) compared beef production over two grazing seasons in Hawaii on almost pure stands of pigeonpea with a mixed grass pasture (Table 2). Since no estimates were given of dry-matter yield and only one stocking rate was used, it is difficult to decide whether

Table 2. Beef production from *Cajanus cajan* compared with mixed grass pastures (*Pennlsetum clan dastinum, Chloris gayana,* and *Axonopus* compressus) over two grazing seasons in Hawaii.

	Trial 1 (13 June-8 Dec 1930)		Trial 2 (22 Apr-9 Nov 1930)	
	C. cajan	Mixed grass	*C. cajan*	Mixed grass
No. of days	179	179	202	202
Animal/ha	1.9	1.1	1.8	1.3
Llveweight gain (kg/head/day)	0.73	0.71	0.77	0.69
Llveweight gain (kg/ha/grazing period)	248	140	280	181

Source: Henke et al 1940.

the grass pastures could have carried a higher stocking rate; however, the fact that the higher stocking rate in the second year gave a lower average daily gain and thus only a small increase in production per hectare suggests that stocking rates were around the optimum. Thus *C. cajan* forage was superior to grass in gain per head, reflecting a higher nutritive value index and also was able to carry a higher stocking rate. This led to a marked superiority in production per hectare.

In Queensland, Australia, Akinola et al. (1975) compared the effects of grazing over two dry seasons in accessions of *C. cajan.* Animal production of *C. cajan* was compared withthat on a similar area of nitrogen fertilized grass (*Setaria sphacelata,* cv. Kazungula). The crop was planted in December 1971, at a density of 18 000 plants/ha (.91 x .6 1m), with adequate basal fertilizer and grazed in the first yearfrom 1 July to 18 October 1972. In the second year the ratoon crop was grazed from 4 June to 6 August 1973 (Table 3). In the first year, which started with an excellent stand, positive liveweight gains were maintained at quite high stocking rates (mean 7.5 animals/ha) for a period of 73 days. Liveweight gains up to 1 kg/head per day were achieved while there was adequate pod and leaf available to the animals. Once the leaf and pod were consumed there was almost no regrowth in this dry cool time of the year and so animals then lost weight until removed.

There was almost no mortality of plants after the first season's grazing, but over the next summer growing period many plants died, possibly from damage received from the first grazing period, but also due to infestation by a scale insect (*Coccus longulus).* By the start of the next grazing season there was a 37% mortality. This was reflected in the much lower total yield of *C. cajan* on offer (Table 3) with, consequently, a much shorter period of grazing. This second grazing caused further mortality, markedly depleting the stand.

Destruction of stands due to infestation by a similar scale insect (C. *elongatus)* have also been recorded in Hawaii (Krauss 1932). However, productive stands were normally maintained forup to 5years with regular defoliation where *C. cajan* was used as a standover forage, but in southern Queensland yield declined drastically in the second grazing season. Thus, we consider *Cajanus* best as an annual forage crop, a conclusion similar to that of Norman et al. (1980), but for different reasons. In the more southern environment the crop was killed by winter frost, but in southern Queensland it was the combination of scale-insect attack and the accumulated effects of the first grazing. Scale-insect attack has not been experienced since that time on single-year crops. It may require two growing seasons *to* build up. Further studies are required.

Both studies (Akinola et al. 1975 and Henke et al. 1940) show that pure stands of pigeonpea forage are ableto support high liveweight gains up to 0.8 kg/head per day when there is adequate leaf and pod material available.

Table 3. Effect of grazing pigeonpea as a Handover forage in the dry Mason on animal production and stand yield and survival.

Grazing period	Stocking rate (animals/ha)	Liveweight gain kg/head/day	Liveweight gain kg/ha/day	DM yield (kg/ha)	Survival (%)
1972					
1 July to 7 Aug	8.5	0.35	3.1	6180	
7 Aug to 11 Sept	6.4	0.32	5.1		
11 Sept to 18 Oct	6.4	-0.05	-0.3	4180	99
1973					
4 June to 25 June	4.7	0.40	1.7	1740	62
25 June to 6 Aug	4.7	-0.25	-1.2	700	30

Source: Akinola et al. 1975.

C. cajan Sown with Grass Pastures

Pigeonpea has limited application in sowings as a mixed grass/legume pasture, first, because it is not competitive in the seedling stage and has a long establishment period, and secondly because it is basically a short-lived perennial. Where it has been used in conjunction with grass pastures it has been planted in cultivated strips and grazed as a dry-season forage. In Southern Rhodesia (Zimbabwe), Gooding (1962) reported the use of pigeonpea as a valuabledry-season supplement. Itwas sown in hedgerow strips through the pasture where 12 ha of pigeonpea plus 14.5 ha of mature grass carried 50 cows for 4 months. Liveweight was maintained even though frosts killed some plants.

Schaaffhausen (1965) planted pigeonpea similarly in Brazilintofurrowsplowedthrougha pangola grass (*Pigitaria decumbens*) pasture. This was grazed during the dry season (June to August) at a stocking rate of 12 animals on 7 ha (1.7 animals/ha) for 60 days with the following results:

- Four bulls gained 0.90 kg/head per day
- Four 2-year olds gained 0.50 kg/head per day
- Four yearlings gained 0.20 kg/head per day

Mean weight gain was 0.52 kg/head per day and 53 kg/ha (60 days).

As in the studies with pure stands, these data again show that when adequate forage is available, pigeonpea is capable of producing high liveweight gains. The reasons for relatively low gain in the yearling group are not clear.

Nutritive Value of Pigeonpea Forage

As a forage legume, pigeonpea is grown particularly as a protein supplement for feeding during periods of low pasture quality. In the vegetative stage the main forage component is leaf, whereas after flowering and seed set the total nutritive value may be increased by the presence of pods and seed. Proximate analyses of various fractions of pigeonpea indicate something of the nutritive value (Table 4).

The actual chemical contents vary depend ing on age and maturity, and on the proportion of various plant components — leaf, stem, flowers, seed, and pods — in the forage. This can be seen in the comparison of mature and young whole tops (Work 1946) (Table 4). The presence of seed and pod in the more mature plants gave higher values of crude protein and N-free extract, due to the difference between the seed and the vegetative fractions in crude protein and carbohydrates. These values are modified in turn by the amount of pod present, which has a relatively low crude protein content but a relatively high nitrogen-free extract.

Differences between components are clearly evident in the range of nitrogen content measured on material from different ages of regrowth by Akinola and Whiteman (1975) (Table 5).

Highest nitrogen contents are found in the leaf fraction, while nitrogen content of stems declines quickly as the dry-matter yield of stem increases. The total yield of nitrogen was always highest in the leaf fraction, but increases in the stem fraction as the plants age, as shown in Table 6.

Table 4. Proximate analyses of pigeonpea components.

		Oven-dry basis (%)					
Component	Moisture (%)	Crude Protein	Crude Fiber	N-free Extract	Fat	Ash	Reference
Fresh green forage	70	23.7	35.7	26.3	5.3	8.7	Krauss (1921)
Whole tops, mature	50	18.8	29.4	40.0	5.2	5.6	Work (1956)
Whole tops, young	52	15.8	31.2	37.7	4.6	5.6	Work (1946)
Seed meal	12	25.3	7.3	61.2	1.7	4.1	Krauss (1921)
Ripe dry seed	10	21.3		63.7*	1.7	4.2	Morton (1976)
Pod meal	13	10.1	40.7	45.0	1.6	3.1	Krauss (1921)
Pods intact		7.0		42.8*	0.4	5.7	Morton (1976)

* Soluble carbohydrate.

The high proportion of the nitrogen yield in the leaf fraction demonstrates the importance of retaining the maximum amount of leaf when curing and transporting pigeonpea hay (Krauss 1921).

The best indices of nutritive value are provided from estimates of in vivo intake and digestibility. There are a few values of digestibility coefficients for forage, but none report intake values (Table 7).

Digestibility values of crude protein are variable, while digestibility coefficients for fiber are low. However, without intake values the nutritional significance of these values to the animal cannot be interpreted.

A better indication of the nutritional value of pigeonpea is provided by the feeding trials of Henke (1943). These trials compared lucerne (*Medicago sativa*) and *C. cajan* tops that included some seed and pod fed to dairy cows (Table 8).

Henke (1948) states that similar milk yields were maintained with similar intakes of concentrate, but with a much higher intake of *C. cajan* forage. However, since milk yields were the same, this suggests that the organic matter digestibility of *C. cajan* must be lower than *M. sativa* orthatthe estimates of TDN intake, which included concentrate, were high in the case of *C. cajan* or low in the case of lucerne. Nevertheless, this study does demonstrate the high quality of *C. cajan* forage and supports the earlier evidence of its ability to support high liveweight gains in beef. Maintenance of high levels of animal production does seem to require a reasonable proportion of seed and pod material in the forage. Henke (1943) found the *C. cajan* produced the highest economic value of digestible nutrients per hectare when compared with *M. sativa, L. leucocephala,* and *Desmanthus* sp. in Hawaii.

In view of its potential to produce quality forage, definitive studies are required to determine the proportion of each component (stem, leaf, seed, and pod) eaten by the grazing or fed animals, and also to determine the true levels of intake and organic matter digestibility of *C. cajan* forage. Examples of these types of studies with *C. cajan* harvest residues are discussed in the next section.

Use of Crop Residues

The material removed from a mature pigeonpea crop by mechanical harvesting contains only 10 to 25% seed, the remaining residue being leaves, stems, and pods. The yield of harvest trash may vary from 5000 to 18 000 kg dry matter/ha, depending on the plant maturity type and the environment in which the plant is grown. The value of this material as an animal feed will depend on the proportions of stem, leaf, and pods. Where hand-harvesting methods are used, the larger stems are usually removed for firewood; the remaining dried leaf and pod represent a source of high-protein, high-fiber forage. Trash of similar composition would normally pass through the harvester where mechanical harvesting is practiced, and can be collected. Where defoliation prior to mechanical harvesting is practiced, the harvest trash after seed removal consists mainly of dried pods. Since there was no information available on acceptability and nutritive value of harvest trash for livestock feeding, the following studies have been conducted at the Univer-

Table 8. Effect of age of regrowth on nitrogen content (% of oven dry) of components of pigeonpea.

Component	Percent nitrogen in regrowth at 4 weeks	16 weeks
Leaf	4.78	3.64
Stem	2.76	1.56
(Pod + Seed)	3.29	2.35

Source: Aklnola and Whiteman 1975.

Table 6. Percentage of total yield of nitrogen (kg/ha) in components of pigeonpea defoliated to 90 cm at 4 frequencies over 48 weeks.

Component	Percentage of total nitrogen yield at defoliation frequencies of 4 weeks	8 weeks	12 weeks	16 weeks
Leaf	64	64	58	53
Stem	22	25	25	31
Pod and Seed	14	11	17	16

Source: Aklnola and Whlteman 1975.

Table 7. Digestibility coefficients for *C. cajan* forages.

Diet	Animal	Digestibility Coefficient (%) Crude Protein	Fat	Fiber	N-free extract	Reference
Immature hay	sheep	71.5				Gooding (1962)
Whole tops, mature	cattle	69.0	69.0	50.0	78	Work (1946)
Whole tops, young	cattle	61.0	47.0	32.0	76	Work (1946)
Crop cut 3 times	cattle	88.0				Oakes & Skov (1962)

Table 8. Lucerne and pigeonpea tops as feed for dairy cows.

Measurement	Forage *M. sativa*	*C. cajan*
Dry matter intake (kg/cow/day)	5.6	10.5
Digest. crude protein intake (kg/cow/day)	0.84	1.38
Total digest, nutrient intake (kg/cow/day)	3.33	7.14
Milk yield (4% fat corrected) (kg/cow/day)	12.9	13.0

Source: Henke 1943.

sity of Queensland to evaluatethese residues as animal feeds.

Nutritive Value of Pigeonpea Pods

The dry-matter yield of pods is approximately equal to that of seed, and its value as animal feed is likely to be limited by low protein and high fiber content. The experiment reported below was designed to investigate the effects of including a good quality pangola grass (*Digitaria decumbens*) hay on the voluntary feed intake and digestibility of pigeonpea pods by sheep. The pigeonpea pods (cultivar Royes) were hand-harvested at maturity, and after seed threshing, were hammer-milled to 1 to 20 mm lengths. Four groups of six mature Border Leicester x Dorset horn wethers were offered one of the following diets ad libitum, pigeonpea pods (PP), pangola grass (PG), 33% PP and 67% PG and 67% PP and 33% PG. The feeding period lasted for 6 weeks, during which time digestibility determinations were made. The chemical composition of the pigeonpea pods (10% moisture), expressed as g/100 g dry-matter, was as follows: crude protein (N x 6.25) 7.5% and ash, 2.9%. Pangola grass hay (15% moisture) contained 16.3% crude protein and 9.4% ash. Table 9 shows mean values for feed intake and nutrient utilization by sheep offered each diet.

Sheep fed 100% pigeonpea pods lost 2% of their initial bodyweight during the experimental period, while sheep in the other groups either maintained liveweight or gained slightly. The voluntary intake of pods and their digestibility were low, and, as a complete diet for sheep, inadequate for maintenance. The protein contents of these pods was low and the protein poorly digested and utilized by the sheep. However, with the inclusion of 33% pangola grass in the ration (67% pods), the intake of digestible nutrients was increased by 92%. It is significant that the inclusion of 33% pods in the pangola grass ration, increased voluntary feed intake by 49% and increased dry-matter digestibility, but reduced crude protein digestibility. The results of this study suggest that although pigeonpea pods fed as a sole d iet are of low nutritive value, the inclusion of small amounts of high quality forage considerably improves nutritive value. Further studies are required to determine whether mineral and grain supplements would further enhance the value of these pods as a productive ration for other classes of livestock.

Nutritive Value of Harvest Trash for Sheep, Goats, and Cattle

Since the harvest trash contains a significant

Table 9. Nutritive value of pigeonpea pods/pangola grass diets for sheep.

Pigeonpea pods in ration (%)	Crude protein in ration (%)	Mean liveweight (kg)	Voluntary feed intake g DM/kg liveweight	Digestibility coefficients (%)		Dietary N stored in body (%)
				Dry matter	Crude protein	
0	16.3	49.4	17.3a*	58.6a	73.3a	31
33	13.4	45.8	25.7b	61.9a	62.0b	35
67	10.4	47.7	25.7b	52.0b	52.6c	34
100	7.5	45.8	15.8a	44.0c	5.3d	N loss
LSD		5.1	3.4	5.2	5.1	8

Source: Bell 1978.

* Values within a column with different letters differ significantly (P<0.05).

Table 10. The nutritive value of harvest trash for goats, sheep, and cattle.

Species	Mean liveweight (kg)	Voluntary feed intake g DM/kg liveweight	Digestibility Coefficients (%)		Dietary N stored in body (%)
			Dry matter	Crude protein	
Goats	39	25.7a*	47.3a	61.8a	40
Sheep	56	21.7b	50.9a	61.8a	44
Cattle	216	25.1a	54.6b	68.8b	48
LSD		3.5	3.6	3.5	6

Source: Quirk 1978.

* Values within a column with different letters differ significantly (P<0.05).

proportion of leaf, this residue would be of higher nutritive value than the pods alone. In the following experiment a pigeonpea crop (cv Royes) was harvested mechanically for seed. The canopy was approximately 1.20 m tall and was cut during harvest at 40 cm. All nonseed material passing through the header was collected, dried and hammer-milled (25 mm screen) prior to feeding to four Hereford steers, six Border Leicester x Dorset Horn wether sheep, and six Angora wethergoats. All animals were offered forage ad libitum in individual metabolism cages for a 6-week period. The forage (9% moisture) contained 13.9% crude protein (N x 6.25), 0.35% phosphorus, 0.06% sulfur and 7.3% ash in the dried plant material. The results from the digestibility trial are shown in Table 10.

Cattle and goats consumed greater amounts of the forage offered than did the sheep. Digestibility of the trash was low, but cattle digested dietary constituents more efficiently than did the other species. However, all species lost approximately 2% of initial bodyweight during the trial period, indicating that this ration was inadequate for liveweight maintenance.

However, when compared with the results from the previous experiment (Table 9), sheep utilized the harvest trash better than the pods alone, and the difference was probably related tothe higherdigestiblecrudeprotein content of the harvest trash. The sulfur content of the forage was below minimum requirements for both cattle (0.10% in dry matter) and sheep (0.14 to 0.18% in dry matter) as recommended by NRC (1970). However, the forage was a rich source of phosphorus. Sulfur requirements are closely related to nitrogen requirements in ruminants, a dietary nitrogen-to-sulfur ratio of 15:1 being adequate for cattle and a ratio of 10:1 adequate for sheep. The nitrogen-to-sulfur ratio in the harvest trash fed was 35:1 indicating that supplementary sulfur may improve the utilization of this forage as a feed for livestock.

All animals were offered an amount of feed approximately 2D% greater than their daily consumption, to provide the opportunity for selective feeding. Table 11 shows mean values for the proportions of feed fractions selected by each species, and the crude protein contents of these fractions. Feed and refusal samples were separated into different particle fractions by dry sieving.

Cattle selected a diet of higher nutritive value by preferential consumption of the finer feed fraction, which contained higher protein and digestible nutrient contents than the coarser fractions. However, all species selected a diet adequate in protein, and the major deficiency of this forage was a low availability of digestible energy and perhaps minerals such as sulfur.

Use of Grain in Animal Feeds

Although the major market for good quality pigeonpeas is likely to be for human consumption, in some countries seed may be directed to animal feeding. Regardless of the market, cracked and pinched grain and the by-products of dhal mills are a potential source of protein for animal feeding, particularly for pigs and poultry. The present high cost of animal protein such as fish-meal, suggests that plant proteins of high quality will be sought as alternatives in the near future. The value of pigeonpea seed for animal feeding has not been investigated as thoroughly as other plant proteins for animal feeds such as soybean meal.

Pigeonpea in Poultry Nutrition

In his review of pigeonpea culture in Hawaii, Krauss (1921) recommended that poultry rations based on cracked pigeonpeas, corn, and small additions of sunflower, peanut, or soybean seed were suitable rations for growing and laying poultry. However, production records were not presented, and the first experimental report of the relative merits of pigeonpea feeding to poultry in Hawaii was published by Draper (1944). In that trial algarroba bean (*Prosopis* spp.) meal and pigeonpea seed meal with 5% leaf meal were used to replace part of a commercial feed for laying hens; algarroba bean meal replaced 20% of the ration (45% barley, 32% alfalfa meal and 23% soybean meal), and pigeonpea seed plus leaf meal replaced 46.5% of the ration (62% barley and cracked corn, 27% alfalfa meal, 11% soybean meal, and 22% meat scrap).

The results of this trial (Table 12) indicate that relatively high rates of pigeonpea can be included in layer rations with little penalty from lowered egg production or mortality. However, the high mortality of birds on all rations and the overall low rate of egg production compared with present-day records indicates a need for further confirmation of these results.

More recently, Springhall et al. (1974) studied the effect of including various levels of pigeonpea seed in chicken rations. The rations used contained 21% crude protein, with isonitrogenous replacement of soybean meal-maize

Table 11. Mean values for the distribution and composition of plant parts selected by goats, sheep, and cattle offered pigeonpea harvest trash.

Particle diameter (mm)	Major plant fraction represented	Crude protein (%)	Distribution of fractions (%) in feed selected				LSD
				Goats	Sheep	Cattle	
>5	Large stems	6.8	12	7.3	6.1	9.3	3.5
2.5-5	Leaf and pod	8.4	42	41.8a*	38.0b	33.5c	2.9
0.5-2.5	Leaf and small stems	12.9	34	38.8	39.5	38.5	3.4
>0.5	Finely ground leaf	21.3	14	12.1a	16.4b	18.9c	
	Crude protein in ration (%)	13.9		14.8	15.4	16.5	0.8

Source: Quirk 1979.

Table 12. Average feed consumption, rate of egg production, and mortality of laying hens fad Algarroba bean meal and pigeonpea meal in Hawail.

Diet	Average feed consumption/ bird (kg)	Average egg production/ year (no.)	Mortality (%)
Basal	45.9	161	27
Algarroba bean meal (20%)	48.6	161	13
Pigeonpea & leaf meal (46.5%)	40.5	150	23
Commercial ration	46.4	176	34

Source: Draper 1944.

Table 13. Bodyw eights, feed conversion, and mortality of chickens fad pigeonpea seed maal for 6 weeks.

Treatment (% pigeonpea)	Body weight (g)		Feed conversion	Mortality (%)
	Hatch	Week 6		
0	39.1	750.9a*	2.6	5
10	39.1	801.1b	2.5	5
20	39.3	776.8b	2.7	0
30	37.7	750.5a	2.8	0
40	38.3	690.7c	3.0	0

Source: Springhall et al. 1974.

* Values in column with different letters differ significantly (P<0.05).

meal with pigeonpea. A summary of these results is shown in Table 13. The inclusion of up to 30% pigeonpea meal increased the growth rate of chickens above the basal growth rate obtained when soybean and corn provided the only protein source. However, growth was depressed where higher levels were used and this was ascribed to amino acid deficiencies in the pigeonpea seed, particularly tryptophan, phenylalanine, and cystine. There have been no reports of toxic factors such as trypsin inhibitors being a problem in poultry feeding. Although further testing must be done with lower quality seed, the information presently available from these two trials (Draper 1944; Springhall et al. 1974) suggests that pigeonpea is a highly acceptable protein source for all classes of poultry rations.

Pigeonpea in Pig Nutrition

There have been no reports in the literature on the use of pigeonpea seed in commercial pig rations, although a program of research has recently been initiated in Australia to investigate the potential of a range of leguminous seeds, including pigeonpea for use in pig rations. Falvey and Visitpanich (1980a) have reported a series of studies in which locally grown pigeonpeas were used to supplementthe diet of native pigs raised by the hill-tribe people of northern Thailand. The traditional diet used in this area has been chopped banana stalk, rice bran, corn, and unsaleable red kidney beans (*Phaseolus vulgaris*) when available. The growth of pigs on these diets was predictably poor, and was considerably improved by the inclusion of pigeonpeas. However, without prior preparation, the seeds are indigestible. The effect of grinding and boiling on the nutritive value of pigeonpea for pigs is shown in Table 14.

In the rations provided, pigeonpea seed comprised 62 to 64% of the dry matter intake. The basal feed was chopped banana stalk and rice bran (1:5). The pigs were started on trial at 6 months of age (38 kg), and the experimental period lasted for 119 days. Although the variability between groups was large, these authors suggested that boiling pigeonpea seed is the most practical treatment under the existing circumstances. They concluded that the large effect of boiling ground pigeonpea indicated the presence of a trypsin inhibitor in the untreated seed. However, there was little effect on the digestibility of seed protein, suggesting that boiling destroyed other toxic factors or increased the availability of digestible energy for growth.

In a second trial, these workers compared a commercial ration with the traditional basal ration supplemented by either red kidney bean or boiled pigeonpea. The results from this experiment are shown in Table 15. The pigs were started on the trial at weaning (3 months; 15 kg) and fed for 168 days. In the rations with legume grain, pigeonpeas and red kidney beans constituted 22to 23% of the diet, a lower rate of substitution than in the previous experiment. It was again shown that inclusion of pigeonpeas in the basal ration (banana stalk and rice bran) increased growth rate of the pigs. Both legume

Table 14. The affect of grinding and boiling of pigeonpea aaad on growth and faad utilization of native pigs in northern Thailand.

	Basal Feed[a]	Basal + ground pigeonpea	Basal + boiled pigeonpea	Basal + ground and boiled pigeonpea
Feed intake (kg DM/day)	0.79	1.19	1.18	1.21
Crude protein intake (kg/day)	0.08	0.20	0.20	0.20
DM digestibility (%)	80.7	81.9	83.0	78.9
Crude protein digestibility (%)	81.8	75.3	74.0	75.4
Liveweight gain (g/day)	25	159	174	205

Source: Falvey and Visitpanich 1980b.

a. Chopped banana stalk and rice bran, 1:5.

Table 15. Feed Intake and growth of highland pigs fed diets containing pigeonpea and red kidney bean.

	Basal	Basal + boiled pigeonpea	Basal + ground & boiled kidney bean	Commercial Ration
Feed intake (kg DM/hd/day)	0.58	0.98	154.86	1.92
Crude protein intake (kg/ha/day)	0.05	0.16	0.14	0.23
DM digestibility (%)	64.3	73.2	77.0	88.2
Crude protein digestibility (%)	51.3	65.4	71.8	83.9
Liveweight gain (g/hd/day)	67	196	154	524

Source: Falvey and Visitpanich 1980a.

grains increased weight gain to the same extent, but the growth rates attained were only 35% of those of pigs on a commercial ration. Higher growth rates would be obtained if corn was offered as the major energy source, but it does seem that pigeonpea seed can be used to satisfy the protein requirements of pigs in this environment.

Use of Dhal Mill By-products

We were unable to find data on the feeding value of dhal milling by-products. Kurien and Parpia (1968) state, "The by-products of dhal milling, husk, powder, and small broken (seed) are usually sold as cattle feed." The husk aspirated after shelling forms about 10% of the total raw material and is sold as cattle feed. The dhal powder is sold at a higher price.

The yield of dhal varies from 65 to 75%, depending on seed size and variety. The by-products consist of: brokens 3 to 8%; powder fraction 12 to 17%; seed husk 10%. The brokens and powder fraction will have a nutritive value probably higher than whole ground seed, since the husk is removed. No data are available on the feeding value of husks (seed testa).

Conclusion

The very high total forage yields from pigeonpea under good growing conditions suggests that further selection and testing of forage varieties my be useful. *Cajanus* is used as forage crop in two main ways, either regularly grazed or cut, or as a standover forage into the dry season. Under regular grazing in Hawaii, very high levels of animal production were achieved, with good persistence of stands, but actual grazing management was not detailed.

Further studies of grazing management and selection of varieties tolerant to grazing damage with ability to ratoon seem to be worthwhile. The possibility of grazing early-sown crops before floral initiation and then allowing the crop to mature for seed production should also be tested.

There are few reliable estimates of the nutritive value of Cajanus forage. There are no values for intake and dry-matter digestibility, which are essential for any interpretation of nutritive value. Dairy production trial results reported by Henke (1943) are inconclusive and further studies are needed to confirm the value of Cajanus forage for dairy cattle. In any feeding trials theforage should be cut at different stages of plant maturity and the proportions of leaf, stem, seed, and pod must be recorded.

Analysis of thefeeding value of harvesttrash materials demonstrates that the feeding value of pods alone, even when hammer-milled, is low. Intake and digestibility of this material was improved with addition of higher quality grass hay. Even though the nutritive value of pods is limited by a high crude fiber content and low digestible crude protein, further studies on feeding pods plus energy and mineral supplements are indicated. The nutritive value of harvest trash that included stem, leaf, and pod was higher than pods alone, but was still quite low compared with good forage and was sufficient only for maintenance. These studies suggested that sulfur deficiency may be limiting the feeding value of pigeonpea trash. Further studies are required to assess the use of sulfur supplementation and to determine whether low sulfur contents are a characteristic of pigeonpea trash. Other minerals might also be limiting. From the limited data, there appear to be no problems in the use of up to 30% of Cajanus seed meal in poultry-growing rations. However, there are almost no data on the use of seed meal for intensive pig production. In village pig-production systems pigeonpea seed meal supplements markedly increased growth rate, compared with the normal deficient diets. In view of its high protein content and favorable amino acid composition, there is an urgent need for more work in nonruminant feeding of pigeonpea.

If approximately 2 million metric tons (tonnes) of pigeonpea seed is processed into dhal in India each year, by-products would be:

Seed husk (10%), 200 000 tonnes

Brokens and powder (15-25%), 300 000 to 500 000 tonnes.

This large amount of by-product is mostly used in cattle feed. It may be more appropriate to use the broken seed and powder fractions in nonruminant feeding, and use the husk for ruminants. Since there are few data on the feeding value of by-products, a research project on this is strongly indicated.

References

ANONYMOUS. 1977. Leucaena: promising forage and tree crop for the tropics. Washington, DC, USA: National Academy of Sciences.

AKINOLA, J. O., and WHITEMAN, P. C. 1975. Agronomic studies on pigeonpea (Cajanus cajan [L.] Millsp.). 1. Field responses to sowing time. Australian Journal of Agricultural Research 26: 43-79.

AKINOLA, J. O., WHITEMAN, P. C, and WALLIS, E. S. 1975. The agronomy of pigeonpea (Cajanus cajan). Commonwealth Bureau of Pastures and Field Crops Review Series No. 1/1975, Hurley, U.K.

AKINOLA, J. O., BIRCH, C. J., WHITEMAN, P. C, and WALLIS, E. S. 1975. Grazing evaluation of pigeonpea. Pages 7-46 in Proceedings, Australian Conference on Tropical Pastures, Townsville, Australia.

BELL, G. D. 1978. The nutritive value of pigeonpea {Cajanus cajan) hulls and cassava (Manihot esculenta) leaf for sheep. University of Queensland Agriculture Department research project report, St. Lucia, Queensland, Australia.

DRAPER, C. I.1944. Algarroba beans, pigeonpeas, and processed garbage in the laying mash. University of Hawaii, Agricultural Experiment Station progress notes 44, Honolulu, Hawaii, USA.

FALVEY, L., and VISITPANICH, T. 1979. Grain legume supplementation and growth potential. Thai-Australian Highland Agricultural Project report 4.

FALVEY, L, and VISITPANICH, T. 1980. Nutrition of highland swine, (ii) Preparation of pigeonpea seed in conjunction with rice bran and banana stalk. Thai Journal of Agricultural Science 13: 29-34.

GARCIA, G. W. 1980. Pigeonpea (Cajanus cajan), its potential as a proteinaceous forage with regard to its agronomy, chemical composition and nutritive value. Faculty of Agriculture report. University of the West Indies, Trinidad.

GOODING, H. J. 1962. The agronomic aspects of pigeonpea. Field Crop Abstracts 15: 1-5.

HENKE, L. A. 1943. Roughages for dairy cattle in Hawaii. University of Hawaii Agricultural Experiment Station Bulletin 92, Honolulu, Hawaii, USA.

HENKE, L. A., WORK, S. H., and BURT, A. W. 1940. Beef cattle feeding trials in Hawaii. University of Hawaii Agricultural Experiment Station Bulletin 85, Honolulu, Hawaii, USA.

HERRERA, P. G., LOTERO, C. J., and CROWDER, L. V. 1966. Cutting frequency with tropical forage legumes. Agricultura Tropicale 22: 473-483.

KRAUSS, F. G. 1921. The pigeonpea (*Cajanus indicus*): its culture and utilization in Hawaii. University of Hawaii Agricultural Experiment Station Bulletin 46, Honolulu, Hawaii, USA.

KRAUSS, F. G. 1932. The pigeonpea (*Cajanus indicus*): its improvement, culture, and utilization in Hawaii. University of Hawaii Agricultural Experiment Station Bulletin 64, Honolulu, Hawaii, USA.

KILLINGER, G. B. 1968. Pigeonpea (*Cajanus cajan* [L] Druce), a useful crop for Florida. Proceedings, Soil and Crop Science Society of Florida 28: 162-167.

KURIEN, P. P., and PARPIA, H. A. B. 1968. Pulse milling in India. I. Processing and milling of *Tur, Arhar* (*Cajanus cajan* Linn). Journal of Food Science and Technology 5: 203-207.

MEHTA, B. V., and KHATRI, P. D. 1962. Accumulation and movement of minerals in pigeonpea *(Cajanus cajan* Millsp.) plant. Journal of the Maharaja Sayajirao University (Baroda) 11: 109-122.

MELLO, F. A. F. de, and BRASIL, M. O. C. do. 1960. Chemical composition of some green manures. An. Esc. Agric, Queiros 17: 347-350. (Portuguese.)

MITCHELL, P. 1953. The pineapple. Queensland Agriculture Journal 77: 125-138.

MORTON, J. F. 1976. The pigeonpea (*Cajanus cajan* Millsp.), a high protein tropical bush legume. Hort science 11: 11-19.

N. R. C. 1970. National Research Council. National Academy of Science, Washington, DC, USA.

NEME, N. A. 1955. Pigeonpea cultivation. Agronomico Campinas 7: 24-28.

NORMAN, M. J. T., SEARLE, P. G. E., DANKITTIPAKUL, N., INGRAM, K.C.,and BASKORO, J. deB. 1980. Evaluation of pigeonpea (*Cajanus cajan*) as an autumn forage for coastal New South Wales. Australian Journal of Experimental Agriculture and Animal Husbandry 20: 55-62.

OAKES, A. J., and SKOV, O. 1962. Some woody legumes as forage crops for the dry tropics. Tropical Agriculture (Trinidad) 39: 281-287.

PARBERY, D. B. 1967. Pasture and fodder crop plant introductions at Kimberley Research Station, W. Australia 1963-1964. 1. Perennial legumes. CSIRO Division of Land Research and Technology Memoir 67/6, Melbourne, Australia.

QUIRK, P. 1979. The comparative value of *Cajanus cajan* harvest trash as a feed for goats, sheep and cattle. University of Queensland Department of Agriculture research project report, St. Lucia, Queensland, Australia.

ROWDEN, R., GARDINER, D., WHITEMAN, P. C, and WALLIS, E. S. 1980. Effects of planting density on growth,light interception andyieldofa photoperiod insensitive *Cajanus cajan.* Field Crop Research (in press).

SCHAAFFHAUSEN, R. V. 1965. Weight increase of Zebu cattle grazing on legumes *Dolichos lablab* and *Cajanus indicus.* Pages 965-968 *in* Proceedings, Ninth International Grasslands Congress, Sao Paulo, Brazil.

SPRINGHALL, J., AKINOLA, J. O., and WHITEMAN, P. C. 1974. Evaluation of pigeonpea seed *(Cajanus cajan)* meal in chicken rations. Pages 117-119 *in* Proceedings, Australian Poultry Science Convention, Sydney, Australia.

WILLIS, J. McG., and BERRILL, F. W. 1953. The banana. Queensland Journal of Agriculture 77: 197-210.

WORK, S. H. 1946. Digestible nutrient content of some Hawaiian feeds and forages. University of Hawaii Agricultural Experiment Station Technical Bulletin 4, Honolulu, Hawaii, USA.

YOUNGE, O. R., and PLUCKNETT, O. L. 1963. Beef production with heavy phosphorus fertilization in infertile wetlands of Hawaii. Page 959 *in* Proceedings, Ninth International Grasslands Congress, Sao Paulo, Brazil.

Discussion — Session 9

Khare:

Denuding of pigeonpea done within a short time after harvest may have certain advantages over milling after a period of storage, when 100-seed weight has changed. What happens when milling is done after a period of storage during which biochemical changes might have taken place and insect infestation and mold attack occurred?

Kurien:

Storage has always helped the dehusking process in both the traditional and the improved methods. But any grain infested or damaged during storage invariably gets crushed during milling. Milling of grain stored $1^1/_2$ to 2 years has given slightly better results; however this needs more systematic study.

B. M. Sharma:

The modern dhal mill installed in Kanpur, U.P., is not working properly. Instead of giving 5 to 7% extra dhal yield, the modern process is giving 5 to 7% less recovery.

Kurien:

The Kanpur dhal mill is not working properly because of lack of proper management. There is nothing wrong with the processing technique.

B. M. Sharma:

How does the taste of the same variety differ when it is processed by two different methods — the conventional, done with water and oil, and the CFTRI, done with hot air — to loosen the husk?

Kurien:

Mild heating enhances the taste and flavor of dhal, and consumers have shown a preference for dhal made by the new method. Here incipient heating loosens the husk without wasting dhal or adversely affecting its flavor.

B. M. Sharma:

The CFTRI model uses costly and scarce energy to loosen the husk by heating. While we are seeking to utilize solar energy in other areas, we are here shifting away from solar energy.

Kurien:

Any source of energy that is cheap and easily available may be used — electricity, furnace oil, firewood, paddy husk. Solar energy can also be used with a suitable heater to heat airto 120 to 180°C. However, the economics and feasibility need to be worked out.

Laxman Singh:

What percentage of the 10 000 dhal mills now operating in India use the improved milling technology devised by CFTRI? How many of these are achieving improved dhal yields?

Kurien:

At present 14 dhal mills are using the CFTRI technique; of these, two report that they are getting 8 to 10% more dhal yield.

Whiteman:

Can you tell me something about the utilization of by-products? What proportion goes to different sorts of animal feeding?

Kurien:

On an equal moisture basis, the yield of husk and powder is 25 to 27% with conventional milling; 17 to 20% with modern milling. It is this difference that goes to the market.

Jambunathan:

Have you tried using solar energy to heat the air in the modern method?

Kurien:

We do not have any data on this aspect yet.

Matanhelia:

In my experience, sun drying is a common practice and a good one. But it has to be done for 8 to 10 days, and we must choose whether we want to invest in the energy or risk the material in the drying yard for 8 to 10 days.

Joshi:

What is the price of the modern dhal mill as compared with the traditional one?

Matanhelia:

On an equal capacity basis, the price of the modern dhal mill will be the same as that of the conventional one. The price of the modern dhal mill is roughly Rs 250 000 (U.S. $30 000).

Joshi:

I wanted tofind out how far we can takethis technology to the rural areas. Do we have any information?

Matanhelia:

The process calls for technical precision — I don't know how far it will be applicable in rural areas.

Williams:

Regarding factors determining price, how large was Dr. von Oppen's sample universe (size of sample and geographic area)? Would these factors be constant throughout India? How well do they apply, considering that 65%of pigeonpea is consumed in the nonmonetary market?

von Oppen:

The analysis of pigeonpea price as a function of quality characteristics was done on a set of about 20 samples collected from traders and millers in Hyderabad. While there may be some regional differences in consumer preferences, we do not expect these to be drastic, so that market prices paid for particular qualities would not be completely different from one region to another. This has been tested in the case of sorghum, and here preferences as expressed in prices were found to be consistent from year to year and across regions. Considering the relatively efficient and well-integrated market network for pigeonpea in India, there is good reason to expect that we shall arrive at similar findings for this crop as we did for sorghum; however, the tests are yet to be done.

Although only about one-third of the pigeonpea arrives in formal market channels, those farmers who don't sell but hold their produce for home consumption are generally well aware of the value of the product they consume — they know its opportunity price. Again, this has been tested and confirmed in the case of sorghum but not pigeonpea.

The reason why we have not proceeded further in this particular line of research for pigeonpea is that we don't have access to a dehulling device for determining the husk content in small samples of pigeonpea. This variable tends to dominate market price, and without a precise measure of husk content, the impact of other relevant variables cannot be accurately estimated.

Tahiliani:

In your map of India, the transport of pigeonpea from north (U.P.) to south and the consumer price graph on production and demand of 1974-75 were not explained. The price of pulses rose in 1977-78 because pulse distribution and storage came under the Essential Commodities Act in 1977.

von Oppen:

It is likely that the price increase for pulses and particularly pigeonpea in U.P. in 1977 was in response to the removal of export restrictions from that state, which brought about an increase in demand, ratherthan in response to the EC Act.

Pushpamma:

Mrs. Bidinger, could you explain first, why the landless laborers are consuming more pigeonpea than medium and large farmers and, second, how the lysine and protein content of the diet met the recommended dietary allowance with only 4.5% protein from legumes?

Bidinger:

The table on pigeonpea consumption by

farm size category shows only children from landless labor households in one village, Dokur, eating more pigeonpea than children of small, medium, and large farm households. In all other villages, the reverse is true. I believe it shows that one cannot always generalize about the plight of the landless laborers. Dokur is a village with more than 30% of its land under irrigation. Paddy is grown, followed by groundnut, both crops that require high labor inputs and provide reasonably good monetary returns. Also, laborers do not go to the fields until about 10 A.M. Until then one can find them at home caring for their children. We find these same children are significantly taller and heavier than the children from farm families (P>.001). The most serious cases of malnutrition we saw were among children of large farm households, where great demands are placed on the women, not only domestically, but as the principal labor recruiters.

Regarding the second question, both lysine and protein requirements can be met because the majority of these are provided by cereals in the diet, and not by pulses. Cereals provide from 69 to 88% of the protein and from 40 to 70% of the lysine, as shown in the table.

Joshi:

Is there any rapid and easy method to determine husk and gum content in pigeonpea? Could these be quantified? Secondly, some time ago experiments conducted on rats, using raw whole pigeonpea seed, showed symptoms like loss of hair and blindness in the test animals. Has the seed coat been analyzed for antinutritional factors?

Jambunathan:

We analyzed a few samples for polyphenols. Most of the polyphenols came from the seed coat. This finding has some relevance in countries where whole pigeonpea seed is consumed.

Srikantia:

The specific question is whether antinutritional factors are present in the seed coat and not present in the cotyledons.

Jambunathan:

We have analyzed only dhal samples for antinutritional factors, not seed coat samples. Only seed coat samples were analyzed for polyphenolic compounds.

Srikantia:

When we talk about the nutritional quality of a particular seed, we tend to forget how the seed is consumed. Cereals and legumes are usually eaten together, and it is this interaction of two foods that determines the nutritive value. Secondly, a number of changes occur during cooking. These aspects should also be studied to determine the overall nutritional potential of such diets.

Shah:

In Gujarat we consume pigeonpea as whole seed (5 to 10 kg/year) and have not faced any problems so far.

Nene:

Whole pigeonpeas are cooked along with meat in some African countries. In our house we have been eating whole pigeonpeas once a week and have had no difficulties!

Katiyar:

Polyphenolic compounds are present in the seed coat. Do they play any role in the mechanism of insect resistance?

Jambunathan:

We do not yet understand the role of polyphenols in insect resistance. As Dr. Reed mentioned in his paper, we are working on this aspect in collaboration with the Max Planck Institute of Biochemistry, Munich, West Germany.

Misra:

Pigeonpea is grown in acid, alkaline, saline, or neutral soils. Does the soil affect the protein content and quality or the cooking quality?

Jambunathan:

Protein content is strongly influenced by soil conditions. We have seen that in chickpea, protein content was considerably reduced when the crop was grown in saline fields.

Srikantia:

Now there is enough evidence from the data obtained at ICRISAT and at NIN (National Institute of Nutrition) that genotypes grown in the same season, underthesame agronomicconditions, but in different soils, would vary in their nutrient profiles. But we still do not know the exact role of the microenvironment—this aspect should also be investigated.

S. P. Singh:

There is a strong feeling in northern India that early-maturing cultivars have poorer cooking quality than late-maturing ones. Is there any chemical evidence to support this?

Jambunathan:

From our village-level survey data, we also got the same impression from the people interviewed. We have not analyzed the cultivars for such characteristics in the laboratory. There were some differences in the protein content, but there was a wide range and some overlapping. So it is difficult to differentiate between early, medium, and late cultivars on the basis of protein content.

C. B. Singh:

What is the extent of losses in protein content during dehulling of pigeonpea? It is reported that in cereals nutrients are lost during pearling because they are present in the outer layers of the seed. Has similar work been done on pigeonpea?

Jambunathan:

We have some evidence to suggest that protein concentration is higher in the cells of peripheral layers of the cotyledons in pigeonpea, and these proteins may be lost during dehulling. More detailed studies are needed.

Srikantia:

We should look at the entire nutrient profile rather than protein alone. The micronutrients, particularly, are very important to us, and we are likely to lose these during processing.

Deosthale:

Regarding milling losses, we at NIN have done some work on rice and pulses. About 50% of the calcium and zinc is lost during milling. But the removal of the seed coat is advantageous in that polyphenolic compounds are present in the seed coat in chickpea and other food legumes, and these compounds have been shown to decrease the iron availability. Considering the widespread iron deficiency anemia in our population, any effort to increase iron availability is important. Thirdly, regarding antinutritional factors, especially oligosaccharides, it has been observed that germination decreases the levels of these sugars, but unfortunately pigeonpea is not sprouted before consumption.

Nerkar:

Does the dhal from white and red pigeonpeas have similar nutritive value? Does white-seeded pigeonpea give higher dhal recovery?

Jambunathan:

My comment was that white seed coats contain less polyphenols than red ones.

Kurien:

We have analyzed a number of white cultivars; most give a slightly higher dhal recovery.

Pushpamma:

I am surprised that cooking time is not as important as flavor in the data you collected. Urban people are highly conscious of cooking time. Was the consumer population you mentioned rural or urban?

Jambunathan:

This observation is based on a small survey of rural consumers and may be biased, as several other factors, such as group opinion, influence answers in the rural areas. This study should be done on a large scale.

Srikantia:

Pulse availability (g/person/day) in the world has come down from 75 g in 1950 to 60 g in 1971 to 51 g today. Now the Indian Council of Medical Research has marked 45 g as the minimum pulse intake requirement. Production of pulses has not kept pace with population increases and there is a grave danger of heavy reduction in pulse consumption in the years to come. The agricultural experts assembled here should address themselves to finding ways of inducing the farmer to grow more pulses, especially pigeonpea.

Session 10

Breeding Methodology and Strategies: an International Perspective

Chairman: A. B. Joshi

Rapporteurs: D. G. Faris
Jagdish Kumar

Pigeonpea Genetic Resources

L. J. G. van der Maesen, P. Remanandan, and Anishetty N. Murthi*

Abstract

Pigeonpea (Cajanus cajan [*L*] *Millsp.*) *genetic resources are assembled, maintained, evaluated, and documented at ICRISAT. As a base for breeding now and in the future, availability and existence has to be perpetuated in the face of genetic erosion due to replacement of landraces, and destruction of habitats of related wild species. This paper reviews collection priorities, evaluation and documentation techniques, maintenance problems, and supply of seeds. The policy is to make germplasm available to any scientist throughout the world. Computer data retrieval is under development in an advanced stage.*

The importance of the pigeonpea (*Cajanus cajan* [L] Millsp.) is sufficiently known; it ranks as fifth pulse crop in the world, although it constitutes just over 4% of reported global pulse production. It is the second most important pulse in India. About 92% of the reported production is from India, while in the West Indies, with ± 1 %, the crop has important cash value (Abrams 1976; Kay 1979; van der Maesen 1981a). In Africa and the Americas, the importance of the pigeonpea tends to be underestimated because areas less than 1000 ha were not reported by the FAO, which ceased publication of separate pigeonpea statistics in 1975. In tropical countries, pigeonpea is often grown as hedgerows, windbreaks, or as a vegetable in kitchen gardens. The pigeonpea, therefore, often augments protein in the diets of those who need it most: the small farmers.

Improvement of the pigeonpea has hitherto banked mainly on selection. The great majority of cultivars presently in use has not been improved in a modern fashion. Institutionally improved cultivars have not yet replaced traditional ones in a big way, although many exist. Pigeonpea breeding continues, and has to bank upon a broad genetic base now and in the future. A large and diverse germplasm collection is therefore necessary, and it needs also to be conserved. Ample awareness of the need for conservation of plant and animal genetic resources is now present with the world's biological scientists. Reference can be made to the general principles in Frankel and Bennett (1970); Frankel and Hawkes (1975) and various releases of the International Bureau for Plant Genetic Resources (IBPGR). ICRISAT has the task of assembling pigeonpea germplasm on a worldwide basis to serve its own and other breeders — a goal that has been pursued since 1973. At the Institute's Genetic Resources Unit a considerable collection has been built up. Collection efforts involved mainly the cultivated pigeonpea, but considerable attention was also given to wild relatives, hitherto classified in the genus *Atylosia,* and other related genera.

Germplasm Available

By mid-1980, 8815 accessions were available, not counting approximately 100 in quarantine transit. Table 1 lists the material by place of origin; Table 2 lists the wild species available. India, as the most important country growing pigeonpeas, accounts for the largest part of the collection and also of the diversity. The firm basis of the collection was the one assembled by the now-defunct Regional Pulses Improvement Program (RPIP) (USDAAJSAID/IARI) and stored at the IARI Regional Station at Rajendranagar near Hyderabad and at several ag-

* Genetic Resources Unit ICRISAT.

Table 1. Pigeonpea germplasm in the ICRISAT world collection.

Country or State	Accession
Australia	47
Bangladesh	26
Brazil	7
Burma	59
Colombia	5
Dominican Republic	6
Ghana	1
Guadeloupe	18
Guyana	1
India	8189
Indonesia	4
Jamaica	18
Kenya	64
Madagascar	1
Martinique	1
Mexico	2
Nepal	128
Nigeria	28
Pakistan	15
Peru	5
Philippines	13
Puerto Rico	45
Senegal	10
Sri Lanka	59
Taiwan	3
Tanzania	5
Thailand	2
Trinidad	22
Uganda	1
USA	3
USSR	2
Venezuela	15
Total	8815
Indian state	
Andhra Pradesh	2396
Assam	112
Bihar	651
Goa, Daman, and Diu	1
Gujarat	125
Haryana	5
Himachal Pradesh	4
Karnataka	275
Kerala	15
Madhya Pradesh	732

Continued

Table 1. *Continued*

Country or State	Accession
Maharashtra	546
Meghalaya	2
New Delhi	111
Orissa	214
Punjab	29
Rajasthan	39
Tamil Nadu	304
Uttar Pradesh	1873
West Bengal	137
Sikkim	5
Unknown origin	613
Total	8189

ricultural universities in India. Initially about 5000 accessions were assembled this way. Numerous collaborators are listed in the introduction to the descriptors (van der Maesen 1980a).

The collection efforts[1] so far involved many trips within India, the home of the pigeonpea (see also van der Maesen 1980b) to secure germplasm of cultivated and wild species as diverse as possible. Other countries visited in the south Asian region were Nepal, Sri Lanka, Bangladesh, Burma, and Thailand. Material from the Americas was mainly obtained from earlier collections or by correspondence. This included missing entries and duplicates from the RPIP collection stored at the National Seed Storage Laboratory, Fort Collins, USA. In Kenya, pigeonpea was the special goal of an expedition while in other African countries pigeonpea was collected as a by-product of expeditions mounted by IBPGR, ICRISAT, and IITA for other crops. Table 3 summarizes collection missions undertaken for the crop and its wild relatives.

1. Pigeonpea collectors were: Anishetty N. Murthi (now with IBPGR), P. Remanandan, R. P. S. Pundir, and L J. G. van der Maesen. Further contributions were made by L. J. Reddy, K. E. Prasada Rao, S. Appa Rao, V. Ramanatha Rao, N. Kameswara Rao, and C. S. Satish Chandra.

Table 2. Wild *Cajaninae* species assembled at ICRISAT.

Species
Atylosia albicans W. & A.
A. cajanifolia Haines
A *goensis* (Dalz.) Dalz.
A *grand/folia* F. v. Muell. ex Benth.
A *lineata* W. & A.
A *marmorata* Benth.
A *mollis* Benth.
A *platycarpa* Benth.
A *rugosa* W. & A.
A *scarabaeoides* (L.) Benth.
A *sericea* Benth. ex Bak.
A *trinervia* (DC.) Gamble
A *volubilis* (Blanco) Gamble
Dunbaria ferruginea W. & A.
D. heynei W. & A.
Rhynchosia albiflora (Sims.) Alst.
R. surea DC.
R. cana DC.
R. densiflora DC.
R. filipes Benth.
R. heynei W. & A.
R. minima DC.
R. rothii Benth. ex Aitch.
R. rufescens DC.
R. suaveolens DC.
R. sp. EC 130746
R. sp. EC 121204
Flemingia macrophylla (Willd) Prain ex Merrill (= *Flemingia congesta* Roxb.)
F. nilgheriensis (Baker) Wight ex Cooke
F. semialata Roxb.
F. stricta Roxb.
F. strobilifera (L.) Aiton
F. tuberosa Dalz.
F. wightiana Grah.
Paracalyx scariosa (Roxb.) Ali

Need for Further Collection

Concerted efforts continue to obtain more diversity and those species not yet represented in the collection. Geographical priorities (as defined by IBPGR, 1976) are South and Southeast Asia, East Africa, and Central America. The pigeonpea ranks crop priority 3 (lowest) in their classification.

The Indian Subcontinent

From the Indian subcontinent — the area of origin and the chief center of diversity of pigeonpea — a reasonable coverage has been achieved. If subsequent data indicate that certain useful characters are linked with certain geographic regions, further collection will be necessary. The habitats of wild species are threatened, and there is immediate need to collect these. For the wild species *Atylosia grand/flora, A. elongata,* and *A. villosa,* more efforts are required in the foothills of the Himalayas, the northeastern states in India, Nepal, and Bhutan. The Khasi hills in Meghalaya, northeastern India, have become agriculturally overexploited, and A *elongata,* a rare species, appears endangered because of pressure on its habitat. This may not yet be so elsewhere, but there again accessibility is limited. From Burma *A. nivea* is needed. More accessions of the species already available are also required to cover intraspecific diversity. In China, Indochina, Malaysia, Indonesia and the Philippines pigeonpea is relatively unimportant butgrown for centuries.A *goensis, A volubilis,* and several more species occur in these countries; hence germplasm needs to be assembled from there.

America and the Pacific

In America and the Pacific the pigeonpea is of rather recent introduction (16th and 18th century respectively). In the West Indies, where pigeonpea is mainly used as a vegetable, African genotypes prevail. Of these a fair number are available, but it is uncertain how much of the existing diversity has been covered in the ICRISAT collection. In 500 years considerable recombination must have occurred, leading to local adaptation.

Africa and the Far East

In Africa and the Far East the pigeonpea has been grown at least about 4000 years (van der Maesen 1980b) and therefore considerable local adaptation must have been obtained by the material in cultivation (or as escape from cultivation) locally. Several wild relatives occur in Africa, most in other genera of *Cajaninae.* More *C. kerstingii* accessions from West Africa

Table 3. Collection missions undertaken for pigeonpea and Its wild relatives.

Year	Dates	Area collected	*C. cajan*	*Atylosia*	Other[a]
1974	Mar	Madhya Pradesh	134		
1975	9 Feb-1 Mar	Madhya Pradesh	18		
	22 Feb-1 Mar	Poona, Bombay Ghats	1	5	26
	30 Mar-9 Apr	Calcutta, Ranchi, Orissa		4	8
	15 Apr-5 May	Madhya Pradesh	125		
1976	22 Jan-1 Feb	Nilgiri and Palni Hills	5	3	138
	9-11 Mar	Tirupathi, south Andhra Pradesh	1	2	15
	22-24 Mar	Puri district, Orissa		1	1
	15 Jul-7 Aug	Kenya	125		10
	7-14 Dec	S. Karnataka, Nilgiri Hills		7	33
1977	10-28 Feb	Tamil Nadu, Kerala	97		
	22 Mar-18 Apr	U.P., A.P., M.P., Orissa	165		44
	23-29 Mar	Orissa, Bastar		8	32
	22-24 Sep	Horseley Hills, A.P.	1		34
	10-18 Oct	H.P., U.P., Himalayan foothills	2	13	135
	15-18 Nov	Nilgiri Hills		1	3
	18 Dec-3 Jan 78	S. Karnataka, Nilgiri Hills	8	12	72
1978	16-23 Jan	Assam, Meghalaya	3	1	18
	21 Feb-10 Mar	Gujarat, Rajasthan	141		
	12-22 Mar	Assam	46		35
	8-16 Apr	Northwestern U.P.	44		
	24-28 Sep	Srisailam, A.P.		2	59
	23-31 Oct	Northern part of W. Ghats		6	72
	27 Dec-9 Jan 79	A.P., Orissa, W. Bengal, Bihar	25	2	
1979	15-26 Jan	Nilgiri, Palni and Shevaroy Hills	2	10	219
	4-21 Mar	Bangladesh	32		173
	11-22 Mar	Bundelkhand (M.P., U.P.)	89		53
	22 Mar-9 Apr	Nepal	100		45
	3-31 May	Australia, Old., N.T.		26	68
	26 Sep-10 Oct	Maharashtra, Gujarat, MP.		10	204
	19 Nov-7 Dec	Northeastern hill states, India	12	4	82
	2-5 Dec	Saurashtra, Junagadh		1	30
	10-12 Dec	Cumbum, A.P.		2	52
1980	27 Jan-9 Feb	W. Ghats	4	20	169
	25 Jan-7 Feb	Southern part of western Ghats		5	82
	7-22 Feb	Sri Lanka	17	15	151
	10-19 Mar	Eastern Ghats		3	15
	7-23 Mar	Northwest Thailand	52	10	14
	3-11 Mar	Burma	6	3	20
	6 Apr-3 May	Western Nepal	35		52
	4-17 Apr	Punjab	7	1	155

a. Include chickpeas, cereals, other *Cajaninae,* and various companion species, some as herbarium only. Not listed are occasional pigeonpeas from explorations targeted for other crops. *Cajaninae* other than *Cajanus* and *Atylosia* are found in numbers much exceeding *Atylosla.*

A.P.-Andhra Pradesh; H.P.=Himachal Pradesh; M.P.=Madhya Pradesh; U.P.=Uttar Pradesh; N.T.=Northern Territory, Australia. Old=Queensland, Australia.

are needed and may offer interesting characteristics to the breeder. The ICRISAT world collection is particularly deficient in pigeonpea germplasm from many African countries.

In Australia, the pigeonpea has recently begun to receive increased attention. Endemic wild relatives of the pigeonpea occur in Queensland, the Northern Territory, and Western Australia; these are insufficiently known and the collection of germplasm has barely begun. Several erect species offer characteristics such as resistance to drought and even to fire. The vast area involved makes exploration time-consuming and expensive. However, many wild pigeonpeas are found in the course of legume collection for fodder purposes and it seems possible that more species new to science may be found in Australia than in other countries where the genus *Cajanus sensu largo* exists. For a comprehensive taxonomic, morphologic, and geographic treatment of the species related to the pigeonpea see van der Maesen (1981b). The species hitherto classified in the genus *Atylosia* are declared congeneric with the pigeonpea.

Evaluation and Utilization

Following the outline presented by van der Maesen (1976), systematic evaluation of pigeonpea germplasm has been carried out every season since 1974-75. Out of the list of characteristics evolved, 32 find a definite place in the computer-based catalog that is under development. The descriptors and descriptor states are given in detail in van der Maesen (1980a). Due to the large size of the collection, evaluation is unreplicated, but every tenth row consists of a check cultivar. Checks used since 1974 are the short-duration cvs Pusa Ageti and T-21; the medium-duration cvs C-11, BDN-1, and ICP-1; and the late cv NP(WR)-15. Detailed morphological observations are taken from three sample plants per row. Each accession occupies a single row; for evaluation plants are spaced 50 cm apart. Rows are 9 m long and spaced 1.5 m apart.

Yield data are taken on a row basis. The highest recorded yield per plant is 750 g. The values, recalculated per plant, are indicative only, because of the unreplicated evaluation. Actual data are stored rather than converted into classes; conversion can be done as and when required.

The germplasm is screened for special purposes. Besides making a general morphological and agronomical evaluation, ICRISAT pulse pathologists and entomologists also screen large segments of the collection each year in sick plots or under unsprayed conditions. Additional information is received from other locations, although the sets grown there are less complete. The main emphasis is on resistance to wilt, sterility mosaic, stem blight, and insects such as the polyphagous *Heliothis* pod borer and the pod fly, *Melanagromyza obtusa.*

Important setbacks to pigeonpea cultivation are waterlogging during part of its growth cycle and salinity. Screening is under way to find resistance or tolerance to these. The ICRISAT microbiologists study nodulation and the biochemists monitor protein content and various other chemical compounds. Even if quality improvement (increasing protein content) does not rate high, quality control to ensure that protein content is not below average is obviously needed. In wild species, some of which have large seeds, high protein content has been found (*Atylosia albicans, A. platycarpa, A. lineata, A. sericea, A. scarabaeoides,* and *A. volubilis*).

One of the major aims of the Genetic Resources Unit screening is to find day-neutral pigeonpeas so that cultivation can be planned independent of daylength, in mid-November, mid-January, and mid-February to coincide with the main photoperiodic response group's cut-off dates determined by ICRISAT's pigeonpea breeders. A group of 160 entries out of more than 4500 screened so far flowered within 60 to 150 days in all sowing dates.

On a field scale, pigeonpea is traditionally grown as an annual; however, the species is actually a short-lived perennial. If pigeonpea could remain in the field for a few years, considerable labor could be saved. However, screening for perenniality is beset with many problems. Although many genotypes are grown as a perennial backyard crop or windbreak (for example in tribal areas in India) stand in a regularly sown crop usually deteriorates after a season due to wilt, sterility mosaic, or ill-defined senescence. In orderto obtain data documenting the behavior and yield decline in perennially grown pigeonpea, several observations were taken on germplasm left for longer than the usual season (June end to March). A formal trial was replanted (after earlier failure due to seasonal water stagnation) in 1979. Ultimately crops 1, 2, 3, and 4 years old will be compared on a trial basis. The cuitivars used for the trial are wilt- or sterility mosaic-resistant or both, to start with the most obvious choice of material.

A replicated yield of some germplasm selections and elite breeding lines was conducted. A field collection from Andhra Pradesh, ICP-6982, gave the highest yield, 1654 kg/ha, while the highest yield of BDN-1 was 1534 kg/ha.

Special-purpose cuitivars, such as early ones, vegetable types, and those with preferred seed characters are under development. Dwarf cuitivars may find a place where the often unwieldy size of the (basically half-wild) pigeonpea could hamper management (spraying) and harvesting (for vegetable use or by machine). The wild relatives are in the process of being introgressed into the pigeonpea either by direct hybridization or via bridge species. Many *Cajanus-Atylosia* hybrids have desirable characters such as disease resistance, insect tolerance, and high protein, but these are difficult to retain after the generations of backcrosses needed to convert the hybrids to productive plants.

Documentation

Documentation of genetic resources can be divided into (1) data bases, to be known before collection and evaluations can be planned, and (2) data resulting from collection and evaluation.

Data to be gathered before collection are statistics and occurrence notes in floras, other literature, and on herbarium sheets. Statistics from literature cover most of the important crop areas in India even down to the district level, and herbarium labels provide useful data for areas where no such statistics are reported. Published data on occurrence of wild relatives *are* scanty, insufficient, or not detailed enough to facilitate pointed collection efforts, whereas the herbarium does provide these data, often in great detail. The necessary study of locations of wild species indicated the insufficiency of the presently known taxonomic status of the genus *Cajanus sensu largo,* which resulted in a revision and full inventory of the diversity of the genus (van der Maesen 1981b).

Data resulting from collection are recorded in travel reports, papers, and the passport catalog of the germplasm. Data gathered in evaluation are cataloged and entered on computer. This vast body of data cannot be published in printed form except for selected items ; however, it is available on computer, and searches can be made when queries arise. Data on evaluations carried out since 1974 are stored on computer at ICRISAT, and our own IDMRS package, the ICRISAT Data Management and Retrieval System, has been developed by J. W. Estes. IDMRS offers many of the same facilities as Executive Information Retrieval (EXIR) and Taxonomic Information Retrieval (TAXIR).

Maintenance and Supply

Maintenance is a major problem in pigeonpea, which is a partly cross-pollinated crop. Up to 40% cross-pollination may occur, and since geographical isolation is infeasible except for a few plots, we resort to selfing of individual plants or branches. Selfed seeds of about 30 plants per accession *are* bulked to constitute the next generation and to reconstitute the population as well as possible. The practice works well, although the selfing — by muslin bags — is costly, laborious, and does not always produce enough seeds. The open-pollinated seeds are used for supply while the obvious off-types of seeds are discarded. Interbreeding within a population is made practically impossible by bagging. Rejuvenation, however, is done by resowing the selfed seeds. In theory, loss of genes is expected to be less than if pigeonpeas were maintained as inbred lines. Seed samples are stored at +4°C and 30 to 40% relative humidity. Long-term storage at -18°C will be available in the second building phase of ICRISAT Center.

Seed supply is a major activity. ICRISAT's world collection of pigeonpea germplasm is available to all interested researchers throughout the world. National and regional institutes and agricultural universities are our major clients. Obviously not every genotype supplied will fit the indentor's requirements for climate, resistances, and quality, but the range supplied can be a sound starting point. The more detailed and precisely framed the seed requests are, the better the chances of the utility of supplied germplasm. Recipients of the seeds are listed in the ICRISAT Annual Reports. Within ICRISAT every year, several thousands of samples are supplied for screening and breeding work. From 1974 to mid-1980 a total of 12 049 samples were supplied, including 4075 outside India.

Conclusions

In 1975 (van der Maesen 1976), ICRISAT's work plan for genetic resources of pulses was presented in outline. The work of the last 6 years has resulted in:

- comprehensive classification at the species level;
- larger diversity of germplasm;
- availability of many more wild species and subsequent interspecific hybrids;
- better understanding of the origin and distribution of the genus *Cajanus;*
- identification of cultivars with desirable traits such as high yield potential, photoinsensitivity, high protein content, and resistance to diseases;
- extensive supply to scientists in many countries;
- a large data base; and
- appropriate germplasm conservation in good storage.

Problems that remain are the difficulty of maintaining pigeonpea as a population in the same constitution as when collected, although the majority of lines is not very heterozygous. Infraspecific classification is difficult because of the variation in habit when grown in different seasons and at different locations, but demand for this classification does not appear to be heavy. Large collections are secured from primary areas of diversity but more material is needed from secondary areas, particularly Africa. Other areas (southeast Asia, South America, and Mexico) are also not well enough represented. Wild species need to be collected in northern Australia, southeast Asia, and West Africa, while from the Indian subcontinent some species and more genotypes or ecotypes of available species are still needed.

Where ecological niches are available and people's taste accepts pigeonpea, the potential for expanding cultivation clearly exists. Improvement for the immediate future is directed towards the main areas of cultivation where yield and stability remain insufficient to feed growing populations. For this purpose a sound and growing base is available.

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References

ABRAMS, R. 1976. Status of research on pigeonpeas in Puerto Rico. Pages 141-147 *in* Proceedings, International Workshop on Grain Legumes. ICRISAT, 13-16 Jan 1975, Hyderabad, India

FRANKEL, O. H., and BENNETT, E. 1970. Genetic resources in plants — their exploration and conservation. IBP (International Biological Programme) Handbook 11. Oxford and Edinburgh: Blackwell. 554 pp.

FRANKEL, O. H., and HAWKES, J. G. 1975. Crop genetic resources for today and to morrow. IBP Handbook 2. Cambridge: Cambridge University Press. 492 pp.

IBPGR (International Board for Plant Genetic Resources). 1976. Priorities among crops and regions. Rome: IBPGR. 24 pp.

KAY, E. E. 1979. Pigeonpea, Pages 322-347 *in* Food Legumes. Tropical Products Institute. Crop and Product Digest 3: 435 pp.

VAN DER MAESEN, L. J. G. 1976. Germplasm collection and evaluation in *Cicer and Cajanus.* Pages 229-237 *in* Proceedings, International Workshop on Grain Legumes, ICRISAT, 13-16 Jan 1975, Hyderabad, India.

VAN DER MAESEN, L. J. G. 1980a. ICRISAT's pigeonpea genetic resources: introduction to the descriptors and data evaluation. ICRISAT, Patancheru, Andhra Pradesh, India.

VAN DER MAESEN, L. J. G. 1980b. India is the native home of the pigeonpea. *in* Liber Gratulatorius in honorem H.C.O. de Wit. Miscellaneous Paper 19.

Agricultural University, Wageningen, the Netherlands: 257-262.

VAN DER MAESEN, L. J. G. 1981a. World distribution of pigeonpea. ICRISAT Information Bulletin (In press).

VAN DER MAESEN, L. J. G. 1981b. *Cajanus* DC and *Atylosia* W.& A. A revision of all taxa closely related to the pigeonpea, with notes on related genera (subtribe *Cajaninae).* Wageningen, the Netherlands: Mededelingen Landbouwhogeschool (In press).

Genetic Improvement of Pigeonpea

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Abstract

Cajanus cajan (L.) Millsp. is predominantly self-pollinated, with natural cross-pollination ranging from 6 to 7%, which leads to generation of genetic variability. Further, somatic variation also seems to augment variability. Taking advantage of such naturally occurring variation, promising varieties have been isolated and released for general cultivation. Their performance, adaptability, and disease reaction will be discussed in detail.

Analysis of data based on germplasm collections revealed that crosses between different maturity groups will be more rewarding. Genetic analysis based on F_1 and F_2 generations of such crosses revealed that:

(1) The E x L and MxL and M x M are the crosses with the most potential for recombining desirable attributes. (2) The nature of gene action is predominantly nonadditive for most characters. (3) The association between yield, height, and maturity are quite strong in the parental groups, the distribution of dominant and recessive alleles being in opposite directions. (4) While the distribution of alleles for yield, plant height, maturity, and seed weight are in opposite directions and well separated, there is complete gradation for the characters, number of pod-bearing branches, length of pod-bearing region and pod number in the F_2 generation. There is a tendency for the associations between yield, maturity, and height to get dissipated, indicating that these linkages may not be very strong and that greater recombination is feasible. (5) There is adequate recombination between different plant types, indicating potential for changes in plant type.

With this kind of genetic information, it now appears that for further improvement of pigeonpea we should concentrate on E x L and M x L crosses. In such crosses, the choice of parents with desirable general combining ability effects will be more fruitful. Inclusion of parents like Prabhat and HY-3A or HY-3C enhance choices for plant type alterations. Amongst crosses involving such parents, only certain combinations could be expected to be of selective value, since the variance due to SCA predominates for several characters. The role of selection indices in pigeonpea improvement is examined. The genetics of plant habit and the scope for selection of high-yielding plant types in improving pigeonpea is examined in detail. The role of genotype x management interactions in maximizing productivity is analyzed in sole and intercropping systems involving pigeonpea.

In breeding food legumes, the first order of priority should be the improvement of productivity, adaptability, and yield stability, to be followed by refinements in nutritional value and consumer acceptability. The yield levels of even the recently evolved pulse varieties are considerably lower than the high-yielding varieties of cereals. Borlaug (1972) appropriately called pulses the "slow runners." Inadequate human selection of superior genotypes and physiological and management limitations have been cited as primary causes for the low productivity of pulses (Swaminathan 1972; Sinha 1973).

Pigeonpea, *Cajanus cajan* (L.) Millsp., in particular has been characterized by excessive vegetative growth. As in cereals, there is a positive regression between yield and maturity

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in *Cajanus* also. Within the species there is considerable variability for plant and flowering habit and various inflorescence attributes. Recombination between diverse maturity groups and inflorescence attributes, together with reduction of excessive vegetative growth and duration could be rewarding. Some of our efforts in this direction will be summarized in this paper.

Genetic Variability

Cajanus is predominantly self-pollinated. Estimates on the extent of outcrossing vary. Our first effort was to study the extent of variability in a representative germplasm collection of 877 types (Reddy et al. 1975). Based on this study, the collections were classified into four maturity groups (Table 1). It was felt that hybridization between different maturity groups would be fruitful.

Further studies revealed that the occurrence of off-types in true-breeding varieties is attributable not only to outcrossing but also to somatic variation, which could also be a potent factor in augmenting variability (Reddy and Rao 1975; Rao et al. 1977). Variation for qualitative as well as quantitative characters was observed in such somatic variants. Cotyledonary shoots totally different from the mother plant and chimeral branches such as a determinate branch on an indeterminate type, variation for flower color and pod striation etc., were recorded. Based on our observations we inferred that such somatic variants could eventually lead to the development of new varieties. Compared with recombination breeding, somatic variants of economic worth, if spotted, could yield rapid results.

Plant Type

Describing variability in *Cajanus,* Shaw (1933) distinguished four types of plant habit "plants erect with inflorescence crowded, plants erect with inflorescence scattered, plants spreading with straggling branches and plants spreading with branches not straggling." The erect habit was reported to be completely dominant over spreading, with a single factor difference. The erects and intermediates were grouped into the dominant class with the spreading class being homozygous recessive. Crowded inflorescence was observed to be dominant with a monofactorial difference, three crowded to one open (Shaw 1936).

We felt that two basic types should be described, indeterminate and determinate, and within those basic types the branching pattern, spreading or erect as well as other variations in plant type could be described (Reddy and Rao 1974). The determinate type was recessive with a single factor difference. Whilethedeterminate types may have an advantage under environments that restrict growth, the indeterminate types may not have to face such limitations in less severe climates. However, there is variation for duration in both the basic types and selection for specified maturity is feasible. The indeterminate types tended to be superior to determinate under our growing conditions (Table 2).

Apart from the determinate or indeterminate habit, branch spread has important implications, since this attribute contributes to competition. There are situations where spreading types are favored and situations where erect types may have advantages; therefore a judicious choice is necessary.

Table 1. Maan characteristics of different maturity groups in pigeonpea.

Days to maturity	Yield (g)	Plant height (cm)	Pods/plant (no.)	100-seed wt (g)
120-135	28.43	132.48	153.33	8.25
135-150	44.26	150.52	182.89	9.68
150-170	71.92	181.28	340.14	10.58
>175	85.20	207.14	579.75	8.80

Tabla 2. Maan Fa valuea for determinata and Indeterminata typaa in *Cajanus.*

Crosses	Plant type[a]	F_2 plants studied	Average values: Plant height (cm)	Pods/plant (no.)	Yield/plant (g)
1. 4785 x T-21	I	157	125.36	199.20	41.08
	D	48	84.38	136.27	24.85
2. 4785 x 4647	I	356	118.70	168.87	27.92
	D	123	78.05	101.93	16.39
3. 4839 x T-21	I	364	149.32	153.41	21.94
	D	134	97.69	103.45	15.49
4. 5245 x 4647	I	269	122.52	133.26	17.48
	D	82	86.94	99.90	9.90
Total	I	1146	128.98	163.69	27.11
	D	387	86.77	110.39	16.66

a. I = Indeterminate: D = Determinate.

Table 3. Parantal and F_1 mean valuas for dlffarent characters in *Cajanus.*

Parents/crosses	Plant height (cm)	Days to 50% bloom	Days to maturity	Pod number	Yield/ plant (g)	100-seed wt (g)	Protein (%)
Parents							
Early (2)[a] Mean	132	73	106	122	31.6	7.6	18.3
Medium (3) Mean	186	91	146	176	50.1	11.8	18.6
Late (5) Mean	238	131	197	175	52.9	15.7	20.0
Crosses							
E x E(1)	151	77	109	191	45.6	7.3	19.1
E x M (6)	151	84	129	233	51.0	9.2	17.9
E x L (10)	174	102	154	213	57.7	10.2	17.2
M x M (3)	178	96	155	259	70.8	11.4	18.0
M x L(15)	224	113	185	298	84.9	12.4	19.3
L x L (10)	269	133	197	315	81.7	14.1	20.7

a. Figures in parentheses indicate number of entries in each group.

Heterosis and Combining Ability

Based on an analysis of the variability in germplasm collections, crosses were made between different maturity groups (Early=E; Medium = M; Late=L) and types differing widely for plant habit (Reddy et al. 1979). The group means are presented in Table 3.

Yield as well as heterosis was maximum in E x L and M x L crosses involving diverse plant types (Reddy et al. 1979). The characters plant height, days to flower and maturity, seed weight, and protein content generally tended to exhibit negative heterosis, although some individual crosses had positive values. Heterosis for pod number and seed yield was generally positive, with some individual crosses showing negative heterosis.

Analysis of F2 means revealed significant differences (Reddy et al. 1979). A summary of the F2 means is given in Table 4. Yield levels of crosses belonging to different maturity groups indicated that yield increases were linear from E x E to E x M, E x L, and M x M. Of the various groups of crosses, the E x L, M x L, and M x M groups appeared more productive and were of greater selective value. The E x L group, particularly, exhibited significant differences for most characters and offered maximum scope for selection.

Combining ability analysis in the F1 as well as the F2 generation (Table 5) (Reddy et al. 1979a, 1979b) revealed that the estimates of variance due to SCA were several times that of GCA for most characters, indicating the importance of nonadditive gene action in influencing most characters. Heterosis breeding may therefore be valuable when techniques for producing hybrid seed are perfected.

Based on GCA effects, it was possible to identify parents such as Prabhat, 4651, HY-3A, etc., which could de rewarding in recombina-

Table 4. F_2 mean values for different characters in between group crosses of *Cajanus.*

Crosses	Plant height (cm)	Days to 50% bloom	Days to maturity	LPBR* (cm)	No. PBB*	Effective pod no.	Yield/ plant (g)	100-seed weight (g)	Yield/ plot (kg)
E x E (1)[a]	145	79	122	61	11	234	51.9	8.0	2.02
E x M (6)	163	87	130	66	10	215	51.8	8.9	2.94
E x L (10)	200	101	147	57	10	227	66.9	9.8	3.95
M x M (3)	201	104	154	70	10	210	64.9	10.7	4.70
M x L(15)	223	117	159	68	11	177	60.6	11.3	3.98
L x L (10)	235	131	237	45	11	199	66.4	12.9	8.56

E = Early; M = Medium; L= Late; LPBR = Length of pod-bearing regions; No. PBB - Number of pod-bearing branches.

a. Figures in parentheses indicate number of crosses involved in each maturity group.

b. Average of approximately 150 plants per plot; Individual observations confined to 15 random plants per plot only.

Table S. Estimates of variance for combining ability in *Cajanus.*

Variance	Character						
	Plant height (cm)	Days to 50% bloom	Days to maturity	Pod number	Yield (g)	100-seed wt(g)	Protein (%)
F_1 generation							
GCA	11494	2503	4909	14559	265	35	93
SCA	42439	11689	28823	72073	6088	141	345
Error	573	0.33	0.66	5562	391	1.21	0.44
F_2 generation							
GCA	-161254*	-38	8489	1849	401	26	
SCA	-107148	82	28648	37395	3789	122	
Error	149359	52	14	897	84	0.2	

a. Negative values in a few cases are due to large sampling error.

tion breeding. Specific M x L and E x L cross combinations are therefore likely to yield recombinants of economic worth.

Character Associations and Selection Advance

Multiple regression analysis of germplasm collections revealed that maturity, pod number, and seed weight are the most important components contributing to yield (Reddy et al. 1975). Graphic analysis of diallel data based on Hayman's (1954) procedures in the F_1 and F_2 generations revealed that while the distribution of alleles for yield, plant height, maturity, and seed weight are in opposite directions and are well separated, in the F2 there is complete gradation for the number of pod-bearing branches, length of pod-bearing region, and pod number. In the segregating material there is a tendency for the association between yield, maturity, and height to become dissipated, indicating that the linkage among these characteristics may not be very strong. There is also adequate recombination among different plant types, indicating potential for changing plant type. Further studies on selection indices of diverse F2 populations revealed that the plant height and seed weight constituted the most important criteria, but that number of pod-bearing branches and length of pod bearing region are also important (Reddy et al. 1979a). Selection based on three- or four-character combinations improved the efficiency (Table 6). Simultaneous selection for several components is beneficial for advancing yields.

Development and Release of Improved Varieties and Their Adaptation

The germplasm collections under evaluation were observed to segregate for several characters. Obviously such variability was the result of natural, and perhaps recurring, outcrossing. Advantage was taken of such variability, and intensive selection was carried out in the most promising collections of early, medium, and mid-late groups, which eventually resulted in the establishment of the HY varieties. A line 2817 similar for several traits segregated only for flower color, seed color, and plant pigmentation. Selection in 2817 resulted inthe isolation of three distinct morphological forms designated HY-3A, HY-3B and HY-3C. Based on our experience we conjectured that somatic variation might have played a role in their origin.

Six improved varieties — HY-1, HY-5, HY-2, HY-4, HY-3A, and HY-3C — have so far been released by us in the States of Andhra Pradesh and Karnataka. The attributes of these varieties are summarized in Table 7.

In the central and peninsular zones, HY-1 and HY-5 have performed extremely well. In Maharashtra, Gujarat, and Madhya Pradesh also the two varieties have performed satisfactorily. These varieties are selections from natural crosses. There is some indication that the differences between HY-3A and HY-3C may be due to somatic variation. In their respective maturity groups, they have relatively bold seeds and hence are greatly valued in the market.

Table 6. Some selection indices and expected genetic advance in *Cajanus.*

Selection index	Expected genetic advance	Relative efficiency (%) over grain yield
0.146 X_1	6.7	
2.151 X2 -0.154 X_7	11.8	76.1
1.454 X_2 +0.075 X_6 -0.190 X_7	13.9	107.5
3.951 X_2 +1.949X4 +0.259 X_5 -0.254 X_7	16.3	143.3
-0.029 X_1 +3.819 X_2 +1.906 X_4 -0.025 X_5 +0.017 X_6 -0.263 *XT*	19.4	189.6

X_1 = Yield/plant (9); X2 = 100-seed weight (g); X_4 = Number of pod-bearing branches (PBB); X_5 - Length of pod-bearing region (LPBR); X_6 = Days to maturity; X_7 = Plant height.,

Table 7. Characteristics of released plgeonpea varieties.

Character	Early		Medium		Mid-late	
	HY-1	HY-5	HY-2	HY-4	HY-3A	HY-3C
Days to flower	80	81	93	85	120	125
Days to maturity	130	130	150	150	180	180
Plant type[a]	Spr	SE	SE	SE	E	SE
Plant height (cm)	115	140	200	170	235	220
Stem pigmentation[6]	P	P	P	P	G	P
Flower color[b]	Y	Y	Y	Y	Y	OR
Pod no./plant	195	200	243	219	174	190
Yield/plant (g)	38	43	59	61	64	68
100-seed weight (g)	10.5	11.2	12.5	12.9	20.0	20.3
Seed color	W	W	W	Br	W	W
Yield ('00kg/ha)	20-22	23-25	26-28	25-28	30-35	30-40
Protein (%)	19.0	NA	20.3	NA	20.2	20.6
Lysine (protein %)	7.62	NA	7.48	NA	7.76	7.44
Leucine (protein %)	6.63	NA	6.73	NA	7.09	6.70
Isoleucine (protein %)	4.34	NA	4.17	NA	4.48	3.56
Methionine (protein %)	1.21	NA	1.22	NA	1.42	1.17

a Spr - Spreading; SE = Semi-erect; *b* G = Green; Y = Yellow; W = White; OR = Orange red
P = Purple; Br = Brown; NA = Not analyzed

Some of these varieties have also been tested in the ICRISAT outreach program, and a list of varieties found promising is presented in Table 8. It is thus seen that the HY varieties have an adaptability across an area much widerthan the area for which they were originally developed.

From ICRISAT studies, HY-3C has been reported to be highly resistant to sterility mosaic virus; HY-2 and HY-3A were resistant. HY-3A and HY-3C have also been reported to be resistant to wilt, but they are susceptible to *Phytophthora* blight.

Table 8. Pigeonpea varieties found promising in different countries.

Country	Cultivar		
	Early	Medium	Mid-late
Nigeria	HY-1	HY-2	
Puerto Rico	HY-1		HY-3C
Burma		HY-2	
Dominican Republic			HY-3C
Liberia	HY-4		
Zambia			HY-3C
Tanzania	HY-1		
Philippines	HY-1		
West Africa (Mali)		HY-2	
Cape Verde Islands			HY-3C
Malaysia		HY-4	

Source: ICRISAT pigeonpea breeding annual report 1978-79.
Blanks mean no information was available.

Genotype x Environment Interactions and Production Technology

Plant Population and Fertilization

The variety HY-3A has an erect habit with no basal branching. To test the response of a variety with this type of growth habit to various plant densities, HY-3A was seeded in 1973 at densities ranging from 50 000 to 150 000 plants/ha. These various plant densities were obtained by using different combinations of row and hill spacings. With the decrease in row and hill spacings, the yield increased progressively. The spacings 60 x 15 cm and 45 x 15 cm corresponding to the plant densities of 111 000 and 150 000 plants/ha respectively, were found to be optimum for giving high yields.

During kharif 1974, four genotypes differing in plant habit and maturity ranges (HY-1: short, spreading, early; HY-2: semi-erect, medium; HY-3A and HY-3C: erect, late) were studied for their response to different plant densities and fertility levels.

HY-3A yielded the most, followed by HY-3C, HY-2, and HY-1 (Table 9). For the fertilizer treatment all genotypes responded optimally to 50 kg P_2O_5/ha, registering mean increase of 25% over the control treatment. With increases in plant density, grain yield also increased progressively. The plant density of 111 000 *and* 150 000 plants/ha, obtained by using 60 x 15 cm and 45 x 15 cm spacing, gave optimum yields.

Further studies on row spacing and plant population with HY-3C and a local variety at Bangalore established the superiority of HY-3C. It has been recommended for release in that region (Table 10).

Suitability to Rabi Cropping

Sengupta and Sen (1980) studied the suitability of several varieties for cultivation during rabi early October sowings in West Bengal. HY-3C and B-7 were the top entries with yields of 2244 and 1954 kg/ha, respectively, in 1978-79.

Table 9. Yield response of *Cajanus* genotypes to fertility and plant density levels.

Genotypes	Yield (kg/ha)	P2O5 levels (kg/ha)	Yield (kg/ha)	Plant density (plants/ha)	Spacing (cm)	Yield (kg/ha)
HY-1	2544	0	2305	55 500	60 x 30	2242
HY-2	2714	50	2906	75 000	45 x 30	2544
HY-3A	2912	100	3052	111000	60 x 15	3019
HY-3C	2848			150 000	45 x 15	3212

Table 10. Seed yiald as affected by cultivar. row spacing, and plant population, Bangalore. kharlf 1975.

Cultivar	Row spacing (cm)	Yield (kg/ha) at plant population/ha of			Mean
		50 000	75 000	100 000	
HY-3C	45	1871	2068	2186	2042
	60	1958	2096	2238	2097
	75	1806	2077	2131	2005
Mean		1878	2080	2185	2048
CO-1	45	916	980	984	960
	60	928	1048	1009	995
	75	993	1089	1052	1045
Mean		946	1039	1015	1000
General mean		1412	1559	1599	

	Cultivar x row spacing	Plant population x	VxRxP
SE±	123	26	62
LSD (5%)	274	53	129
CV%	17.10	5.00	

Intercropping Systems

Pigeonpea is usually a component of intercropping systems with main crops of sorghum, groundnut, etc. The performance of pigeonpea in various intercropping systems has been summarized by Reddy et al. (1977b), Tarhalkar and Rao (1979), and Rao et al. (1979).

From an analysis of a large number of sorghum-based intercropping studies all over India, Rao and Rana (1980) established that while 95% of the sole-crop sorghum yield was realized under intercropping, the drop in the yields of pigeonpea as an intercrop compared with its performance as sole crop was steep. Hence, there is considerable scope for improving the pigeonpea genotype in such a way that its yields do not show a sharp decline under companion cropping. An analysis to this effect has been made by Rao et al. (1979), who established that reduction of basal branches and increased concentration of inflorescence clusters towards the top as in HY-3A might alleviate this situation to some extent. Relative performance and stability of HY-2, which has basal branches, and HY-3A, an erect type with no basal branches, is depicted in Figure 1. This is only to illustrate that there is considerable scope for genotypic manipulation of the intercrop so as to achieve minimum reduction of yield compared with its sole-crop yield.

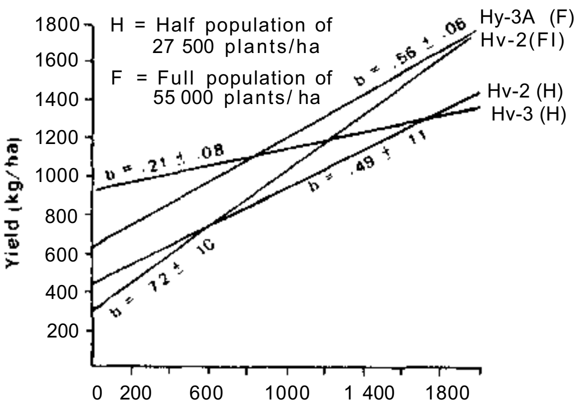

Figure 1. Average yield (kglha) in five planting patterns.

Breeding Superior Pigeonpea Cultivars

Inadequate selection of superior genotypes appears to be the primary reason for nonavailability of high-yielding varieties of *Cajanus.* Utilization of diverse germplasm sources to correct excessive vegetative growth and duration can lead to the evolution of new plant types with a better distribution of dry matter between vegetative and reproductive portions and furnish the genetic means for upgrading the present yield levels of this grain legume.

The breeding system in *Cajanus* is predominantly self-pollination, with varying levels of outcrossing. Somatic variations can also augment genetic variability. Based on systematic genetic studies, Reddy et al. (1977a) outlined procedures for breeding superior pigeonpeas. The salient features of these studies are:

1. The E x L, M x L, and M x M *are* the crosses with the most potential for recombining desirable attributes.
2. The nature of gene action is predominantly nonadditive for most characters.
3. The association between yield, height, and maturity are quite strong in the parental groups, the distribution of dominant and recessive alleles being in opposite directions.
4. While the distribution of alleles for yield, plant height, maturity, and seed weight are well separated, in the F_2 there is a complete gradation for the characters, number of pod-bearing branches, length of pod-bearing region, and pod number. In the segregating material, there is also a tendency for the associations between yield, maturity, and height to become dissipated, indicating that these linkages may not be very strong and that extensive recombination is feasible.
5. There is adequate recombination between different plant types, indicating potential for changes in plant type.

With this kind of genetic information, it now appears that for further improvement of pigeonpea we should concentrate on E x L and M x L crosses. In such crosses again, choice pf parents with desirable general combining ability will be more fruitful. Parents like Prabhat and HY-3A provide many choices for plant type alterations. Among crosses involving such parents, only certain combinations could be expected to be of selective value, since the variance due to SCA predominates for several characters. Thus, handling a sufficiently large number of crosses of this type and selecting on F2 performance as a basis for further selection could be fruitful.

It has been frequently stated that introduction of male sterility genes and chemosterilants may be used to promote random mating and break linkages. In *Cajanus,* while associations between maturity and yield are quite strong in the parental groups, there is adequate recombination in the F2. Thus, breaking up of linkages may not present serious problems. Selections for length of pod-bearing region, number of pod-bearing branches, and pod number, which have a wide range of recombination, could influence ultimate yields and improve the harvest index. Through an alteration of the plant type by combining early and determinate Prabhat habit with the less branched HY-3A type, with terminal clusters, it should be possible to reduce both duration and the vegetative frame.

Since the nature of gene action for most attributes is predominantly nonadditive, exploitation of heterosis is highly desirable. To date, genetic male sterile genes are available, but the procedures for the development of commercial hybrids need to be streamlined. Discovery of cytoplasmic genetic male sterility could speed this process.

Resistance to pod borers would be a desirable attribute, and if incorporated, could prevent substantial losses. Available sources of disease resistance also should be used to advantage.

Pigeonpea being predominantly an intercrop, specific breeding procedures for intercrop systems so as to minimize yield losses under inter-cropping compared with its sole-crop yield need to be designed and suitable genotypes developed.

References

BORLAUG, N. E. 1972. Building a protein revolution of grain legumes. In nutritional improvement of food legumes by breeding. Pages 7-11 *in* Proceedings, Conference of Protein Advisory Group. 3-5 July 1972, FAO, Rome, Italy.

HAYMAN, B. 1.1954. The theory and analysis of diallel crosses. Genetics 39: 789-809.

RAO, N. G. P., and RANA, B. S. 1980. Sorghum based cropping systems to meet shortages of pulses and edible oilseeds in India. Current Science 49 (16) : 622-626.

RAO, N. G. P., RANA, B. S., and TARHALKAR, P. P. 1979. Stability, productivity, and profitability of some intercropping systems in dryland agriculture. Presented at the International Workshop on Intercropping. ICRISAT, 10-13 Jan 1979, Hyderabad, India. Proceedings in preparation.

RAO,N.G.P.,REDDY,R.P.,and HARINARAYANA,G. 1977. Somatic variation in grain legumes. Indian Journal of Genetics 37 : 457-59.

REDDY, R. P., and RAO, N. G. P. 1974. Inheritance and relation with some yield components of plant and flowering habit in *Cajanus.* Indian Journal of Genetics 34 : 94-99.

REDDY, R. P., and RAO, N.G. P. 1975. Somatic variation in *Cajanus cajan.* Current Science 44 : 816-817.

REDDY, R. P., SINGH, D., and RAO, N. G. P. 1975. Character association in pigeonpea. Indian Journal of Genetics 35: 119-122.

REDDY, R. P., AZEEM, M. A., and RAO, N. G. P. 1977a. Breeding superior pigeonpeas. *In* Proceedings, Third SABRAO Conference, 11-18 Feb 1977, Canberra, Australia.

REDDY, R. P., TARHALKAR, P. P., and RAO, N. G. P. 1977b. Improved pigeonpea varieties for mono- and intercropping. Indian Farming 27(9): 3-6.

REDDY, R. P., AZEEM, M. A, RAO, VIDYASAGAR, K., and RAO, N. G. P. 1979a. Combining ability and index selection in F2 generation of pigeonpea crosses. Indian Journal of Genetics 39: 247-254.

REDDY, R. P., RAO, VIDYASAGAR K., and RAO, N. G. P. 1979b. Heterosis and combining ability in pigeonpea. Indian Journal of Genetics 39: 240-246.

SENGUPTA, K., and SEN, B. K. 1980. Arhar in West Bengal as a rabi crop. Indian Farming 29 (10): 9.

SHAW, F. J. F. 1933. Studies in Indian pulses (3) the types of *Cajanus indicus* Spreng. Indian Journal of Agricultural Science 3: 1-36.

SHAW, F. J. F. 1936. Studies on Indian pulses: The inheritance of morphological characters and of wilt resistance in arhar (*Cajanus indicus* Sprang). Indian Journal of Agricultural Science 6: 139-187.

SINHA, S. K. 1973. Yield of grain legumes — problems and prospects. *In* Proceedings, Second SABRAO Congress, Indian Journal of Genetics (Special issue).

SWAMINATHAN, M. S. 1972. Basic research needed for further improvement of pulse crops in South East Asia. Pages 61-68 *in* Nutritional improvement of food legumes by breeding: Proceedings of Protein Advisory Group. 3-5 July 1972, FAO, Rome, Italy.

TARHALKAR, P. P., and RAO, N. G. P. 1979. Genotype-plant density considerations in the development of an optimum intercropping system for sorghum. Presented at the International Workshop on Intercropping. ICRISAT, 10-13 Jan 1979, Hyderabad, India. Proceedings in preparation.

Pigeonpea Breeding in the All India Coordinated Programme

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Abstract

Pigeonpea improvement in India on modern lines started with the gathering of an extensive germplasm in the 1920s at the Imperial Agricultural Research Institute then at Pusa, Bihar. Between 1940 and 1950, several schemes were sponsored by the /CAR at important pigeonpea-growing centers; as a result of systematic breeding work a number of improved varieties were developed. With the inception of the All-India Coordinated Programme, a multidisciplinary, multicenter approach was adopted for the improvement of this important pulse crop. This approach facilitated extensive exchange of germplasm as well as varieties developed in the different regions and a number of varieties of wide adaptation have been identified.

The major approach in the Indian program has been to fit the crop into as many niches in the country's farming systems as possible. The extraordinary plasticity of the taxon led to the development of a series of trial sets to evaluate the genotypes for suitability to particular growing period-cum-cropping situations. The process often began with the recognition of a possible niche and identification of an archetype variety that might fit this niche. Subsequently, more and better genotypes were identified or developed for each group. In addition to the ability to fit the agroclimatic limits, other characters that have been looked for are lower insect or disease susceptibility, more acceptable seed sizelquality, ability to stand greater population pressure or other agronomic inputs and where possible, a measure of yield superiority. Both conventional breeding procedures as well as induced mutations have been utilized. Some of the major approaches in the Indian program have been summarized in this paper.

Pigeonpea or red gram, popularly known in India as arhar or tur and an important source of protein in the cereal-based vegetarian diets of India, is largely eaten intheform of split pulse or dhal. Arhardhal isa preferred component of the rice diet and complements the nutritional value of cereals. In common with other legume crops, pigeonpea is, and has always been, a very important component of the farming system in India because of its ability to fix atmospheric nitrogen. Being a deep-rooted crop, it can thrive well under rainfed conditions, and its roots open up the soil and improve the soil structure.

Over 90% of the total world production of pigeonpea comes from India. The total area in India during 1978-79 was around 2.7 million ha, with a production of about 1.9 million metric tons (tonnes) forming 18% of total pulse production in India. The major producing states are Uttar Pradesh, Maharashtra, Madhya Pradesh, Karnataka, and Bihar, accounting for 90% of India's production. It is to be noted that the crop statistics are not very precise, the major area under pigeonpea being in various mixtures. In addition to the reported figures on area and production, there is some unreported acreage planted on bunds, as hedges, as a backyard crop and in other fill-in situations, which go completely unaccounted for.

Pigeonpea is a relatively new crop in India; the earliest reference to this crop in Indian literature goes back only to the third or fourth century A.D., where it has been referred to as

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tuvarica. Adhaki, a synonym, has been cited in *"Susruta Sanhita,"* the Sanskrit medical text dated around the sixth century A.D. The present-day local names of the crop in India can be divided in two major groups that appear to have been derived from the two unrelated ancient names, *tuvarica* and *adhaki; tuvary, tuvara, tura, tur, thor, thogari,* etc., forming one group, and *arhar, rahar, rahri,* etc., another.

History of Early Pigeonpea Improvement in India

Pigeonpea improvement work started in India at the beginning of this century at centers of agricultural research in some of the major pigeonpea-growing states. Systematic investigations carried out at the Imperial (now Indian) Agricultural Research Institute (IARI) then located at Pusa, Bihar, resulted in the isolation of "unit species" from field collections, including types having resistance to wilt even in sick plots. Shaw et al. (1933) analyzed a comprehensive collection of such fixed types originating from different pigeonpea-growing regions of India. They gave a detailed classification; a key based on flower, seed, and plant characters; and full morphological description of 86 types isolated from populations from different pigeonpea-growing regions of the Indian subcontinent and identified after a critical evaluation. Mahta and Dave (1931) made a similar study of the landraces in the then Central Provinces (now part of Madhya Pradesh). They also provided morphological description of the various types in cultivation and obtained information on the floral biology of the crop. These workers also broadly distinguished two forms, one short and ripening early, and the other tall and maturing late.

The Indian Council of Agricultural Research sponsored several schemes in the 1940s and 1950s for pigeonpea improvement. A detailed account of the work done inthis period has been given by Pathak (1970). The important centers of work on pigeonpea were Vijayanagaram and Warangal in Andhra Pradesh; Vijapur, Nadiad, and Surat in Gujarat; Indore and Gwalior in Madhya Pradesh; Dharmapuri in Tamil Nadu; Niphad, Parbhani, and Mohol in Maharashtra; Hebbal, Annegeri, and Raichur in Karnataka; Kanpur in Uttar Pradesh; and Berhampore in West Bengal. Several improved varieties were evolved as a result of the systematic breeding programs at these centers.

Pigeonpea Improvement in the Coordinated Programs

After a critical review of the work at different centers during the decade 1943-53, the Indian Council of Agricultural Research (ICAR) concluded that considerable progress has been made and a large number of useful pigeonpea varieties produced. This was not, however, reflected by any substantial increase in the all-India production of the crop. A careful analysis of the situation suggested that this may have been largely because the activities at different centers and in different disciplines at these centers, were carried out in isolation. Also, the scientists appeared to be working with limited germplasm and for limited situations.

This analysis showed the need for concerted efforts at the improvement of pigeonpea and other pulses on an all-India level. With this in view, the ICAR sponsored a multidisciplinary All India Coordinated Project for Improvement of Pulses at the end of 1965. The project started with 15 centers. In subsequent phases, the coverage was intensified, and in the Sixth Five-Year Plan, it is expected that there will be a total of 31 centers.

Genesis and Evolution of Coordinated Varietal Trials

As the first step, the coordinated program set out to evaluate the available improved genotypes over a wide range of environments. Uniform all-India trials were planned during 1966-67; under this scheme, a common set of varieties was tested at 22 locations all over the country. Later, three sets of trials (ACT-1, ACT-2, and ACT-3) were developed, based on the maturity of genotypes included and consequently their suitability for different agronomic situations. The list of varieties and number of locations at which the trials were tested during different years is given in Table 1.

At the outset, allocation of varieties to maturity groups was not precise. For some years, varieties of 180 to 200 days' maturity such as Mukta, No. 148, ST-1, and Sharda were tested in

Table 1. ACTs conducted since the beginning of the All India Coordinated Research Project for the Improvement of Pulses.

Year	No. of varieties in set	No. of locations	Varieties included	Varieties superior over control
EACT (Archetype: Prabhat)				
1976-77	6	22	UPAS-120, Prabhat, Pant A-2, Pant A-3, Pant A-1, T-21	UPAS-120, Pant A-1
1977-78			Not conducted	
1978-79	12		Prabhat, ICPL-1, ICPL-2, ICPL-3, ICPL-4, H 73-20, H 76-20, H 76-35, H 76-53, HPA-2, UPAS-120	ICPL-1
ACT-1 (Archetype: T-21)				
1968-69	5	23	T-21, BR-183, Khargone-2, ST-1, Sel. 1141	ST-1, Sel. 1141
1969-70	12	24	P-4785, P-4758, P-4839, T-21, S-5, S-8, S-10, R-60, Khargone-2, No. 148, ST-1, Sel. 1141	S-8, R-60, Khargone-2
1970-71	13	31	P-4785, P-4758, P-4839, T-21, S-5, S-8, S-10, R-60, Khargone-2, No. 148, ST-1, Sel. 1141, BR-183	P-4758, Khargone-2, No. 148, S-8
1971-72	14	32	BR-172 plus set of 1970-71	S-5, R-60, S-8
1972-73	11	43	T-21, Prabhat, S-5, S-8, BS-1, Khargone-2, No. 148, BR-183, BR-172, UPAS-120, Co. 1	Prabhat, No. 148, BS-1
1973-74	9	47	T-21, Khargone-2, No. 148, UPAS-120, Prabhat, BS-1, Pant A-2, Pant A-3	Pant A-3, BS-1, T-21, Khargone-2
1974-75	12	27	T-21, UPAS-120, Prabhat, BS-1, Pant A-1, Pant A-8, Pant A-9, Hy-1, Pant A-2, Pant A-3, PS-11, DL 74-1	BS-1, UPAS-120 DL 74-1, Hy-1
1975-76	12	35	1974-75 set repeated	BR-172, DL 74-1, Hy-1
1976-77	10	30	JA 9-19, BR-172, DL 74-1, 4-64, 4-84, K-10, H 73-20, Hy-5, C-53, C-159	DL 74-1, 4-84, JA 9-19
1977-78	16	20	JA 9-19, C-159, C-53, Hy-5, H 73-20, 4-84, 4-64, DL 74-1, TT-2, TT-4, TT-5, TT-6, T-21, Co-3, Hy-1, KH-10	4-84, Co. 3, JA 9-19
1978-79	17		4-84, 4-64, DL 74-1, T-21, ICPL-5, ICPL-6, ICPL-7, ICPL-8, Hy-1, Hy-5, Sehore 68, Sehore 197, Co-3, TT-2, TT-4, TT-5, TT-6	4-84, DL 74-1, Hy-5, 4-64, Hy-1
ACT-2 (Archetype: No. 148)				
1968-69	9	23	BR-60, B-7, PM-1, SA-1, C-11, N-84, PT-301, N 290-21, No. 148	PM-1, SA-1, C-11, R-60
1969-70	10	23	R-3, R-10, S-28, R-85, C-11, GWL-3, T 15-15, B-7, PM-1, PT-301	PM-1, B-7, R-85

Continued

Table 1. *Continued*

Year	No. of varieties in set	No. of locations	Varieties included	Varieties superior over control
1970-71	10	24	R-2, R-10, S-28, R-85, C-11, GWL-3, T 15-15, B-7, PM-1, PT-301	S-28, B-7, PT-301, PM-1
1971-72	15	24	R-3, R-10, S-28, R-85, C-11, GWL-3, T 15-5, B-7, PM-1, PT-301, EB-38, Kank H-3, KH-9, BK-65, C-28	
1972-73	9	29	R-60, No. 148, C-11, C-28, ST-1, T 15-15, BR-65, B-517, SA-1	
1973-74	18	32	R-60, C-11, C-28, ST-1, T 15-15, SA-1 PH-41, PH-39, PH-61, PH-65, PS-4, PT-301, 5039, 4806, EB 38-70, AS-44, 4488, BR-65	C-28, ST-1, R-60, PT-301
1974-75	22	15	Mukta, C-11, EB 38-70, BR-65, No. 148, PS-41, PS-43, PS-51, PS-54, PS-61, PS-65, PS-66, PS-71, Hy-2, Hy-4, JA-1, JA-3, C-28, JA 9-19, Khargone-2, PM-1, ST-1	JA-3, PS-41, PS-51
1975-76	20	30	Mukta, C-11, ST-1, EB 38-70, BR-65, No. 148, BDN-1, PS-41, PS-43, PS-51, PS-54, PS-61, PS-66, PS-65, PS-71, Hy-2, Hy-4, JA-1, JA-3, Local	BDN-1, Mukta, ST-1
1976-77	17	30	ST-1, Hy-2, Hy-4, Hy-3A, Hy-3C, BDN-1, C-11, PS-11, JA-3, Mukta, EB 38-70, No. 148, ICPL-1, ICPL-7, 6997 Sel., AS 71-37, PM-1, SA-1	C-11, AS 71-37, ST-1
1977-78	14		Hy-2, Hy-4, BDN-1, BDN-2, C-11, No. 148, JA-3, JA-5, JA-8, JA-15, TTB-7, Mukta, AS 71-37, Local	BDN-1, AS 71-37, JA-3, JA-8
1978-79	20	31	Hy-2, Hy-4, BDN-1, BDN-2, C-11, No. 148, JA-3, JA-8, AS 71-37, JA-15, JA-6, Lam RG-30, Lam RG-36, GS-1, ICP-185-9, ICP-2223-1, ICP-2223-5, Sehore 75-4, MAUW-1, MAUW-175	Lam RG-30, Lam RG-36, GS-1
ACT-3 (Archetype: NP(WR)-15)				
1968-69	8	23	T-7, T-17, 7-S, 2-E, GWL-3, NP (WR)-15, S-103, NP-69	T-7, 2-E, GWL-3
1969-70	9	24	T-7, S-103, T-17, NP-69, 7-S NP (WR)-15, R-7, R-98, S-29	T-17, S-103, T-7 NP-69
1970-71	9	15	T-7, T-17, S-103, NP-69, NP (WR)-15, R-7, R-98, S-29, 7-S	T-17, 7-S, T-7, S-29
1971-72	10	15	T-7, T-17, S-103, NP-69, NP (WR)-15, R-7, R-98, S-29, 7-S, K 35/5	
1972-73	12	19	T-7, TT-7, S-103, R-3, R-98, NP (WR)-15, S-29, 7-S, K 35/5, 1258, 1234, PM-1	

Continued

Table 1. *Continued*

Year	No. of varieties in set	No. of locations	Varieties included	Varieties superior over control
1973-74	16	12	T-7, T-17, NP (WR)-15, S-29, B-517, 7-S. 1258, 1234, PM-1, GWL-3, KWR-1, Sel. 73, GC 6826-5, GC-6800, GC-6804, GC-6842	1258, T-17, NP (WR)-15
1974-75	14	14	T-7, T-17, NP (WR)-15, S-29, B-517, 750, 1234, 1258, PM-1, KWR-1, K-23, K-16, Hy-3A, Hy-3C	T-7, KWR-1, B-750
1975-76	15	12	T-7, T-17, NP (WR)-15, S-29, B-517, 7-S, 1234, 1258, GWL-3, KWR-1, K-23, K-16, Hy-3A, Hy-3C, PM-1	1258, 1234, T-7
1976-77	22	10	Old set of 14 varieties+ GWL cultures and 5 Pusa cultures	1258, K-23
1977-78	18	12	NP (WR)-15, AS-29, PS-43, PS-65, PS-66, PS-71, PS-41, JA-7, GWL-3, B-517, No. 1234, No. 1258, T-7, K-73, K-16, K-28, BK-172, K-23	K-23, AS-29

ACT-1, with other varieties of 150 days' maturity. It soon became all too clear that the maturity of pigeonpea varieties is very much influenced by the latitude of the location, moisture stress, and temperature prevailing at the time of flowering and fruiting. Maturity period of the same variety is considerably reduced in lower latitudes and a variety of 180 to 190 days' maturity in the north may take hardly 150 days in the south.

Arhar Coordinated Trial-1 (ACT-1)

This set was constituted for the first time in 1968-69 with five early varieties, maturing in 150 to 160 days. Interest in such early-maturing varieties at the all-India level is a fairly recent development in pigeonpea breeding research, though the existence of early-maturing types was known as early as the 1920s. The variety T-21, developed at Kanpur in Uttar Pradesh, was the archetype for this maturity group.

The development of such early-maturing varieties has played a significant role in fitting arhar in new cropping sequences such as arhar-wheat. The postponement of the optimum sowing time of wheat by about a month, with the introduction of relatively less photo-sensitive Mexican wheats, also contributed significantly to making this sequence a real possibility.

Variety T-21 was selected from the cross (T-1 x T-190) as early as 1961, but extensive all-India testing was done only from 1968 onwards, with the initiation of the coordinated programs. T-21 has a semispreading and loose plant type with indeterminate branching pattern; its seed is small and not liked by millers. Other varieties that gradually came to be tested in ACT-1 were Pusa Ageti, BS-1, Khargone-2, and BR-183. Pusa Ageti was developed from a cross, Brazil 1-1 x NP-69, at IARI and released in the year 1971. It is an early-maturing (150-160 days), relatively dwarf and compact variety, having a determinate habit. This variety was well accepted by farmers because of its bolder seeds, compared with T-21, but it showed high pod-borer damage due to the clustering of pods. BS-1 is reported to be a selection from T-21 for compact habit and early maturity.

Extra-Early Arhar Coordinated Trial (EACT)

Experience with the ACT-1 varieties showed that in some seasonsthe fruiting was prolonged and many of the varieties of this group did not mature sufficiently early to allow planting of wheat at the optimum time. Thus a need was felt for developing even earlier maturing types that would ripen well enough in time to allow for the uncertainties of environmental factors. Prabhat, the first variety of this extra-early maturity group (125-130 days) is a very erect, compact type, with determinate branching pattern. But again because of clustering of pods, it is highly susceptible to pod-borer damage. Almost at the same time, UPAS-120, a selection from P-4758, was developed at Pantnagar, of similar maturity as Prabhat but with a plant type like T-21. Seed size in both these extra-early varieties was in general smaller than in the ACT-1 group. In 1973 two more varieties with extra-early maturity. Pant A-2 and Pant A-3, became available. Pant A-3, besides being extra-early in maturity, had bold seed size (8.5 g/100 seeds), an improvement over the earlier extra-early varieties, resistance to sterility mosaic, and some tolerance to anthracnose. However, the maturity of the variety was not quite synchronous, and harvest was at times delayed because of staggered fruiting.

By 1974-75, enough extra-early genotypes had been generated in the program to allow EACT to be constituted as a separate set for identifying suitable varieties for the specific arhar-wheat rotation, especially in the northwestern plains zone. These varieties were also found to be useful in pushing arhar cultivation to the states of Punjab, Rajasthan, and Haryana, where, because of frost, the crop was never cultivated earlier, as well as to the northwest foothills and adjoining regions, where T-21 group varieties could not find a place. Varieties of the EACT group are also becoming increasingly important in newly developed cropping sequences, such as late kharif (rainy-season) planting and early rabi (postrainy) planting in rice fallows in the eastern and southern parts of the country. Several new short-duration varieties such as DL 78-1, DL 78-2, AL-15, H 76-19, H 76-35, H 76-53, and ICPADL-1 developed or identified in recent years, have shown promise at different centers and they are being extensively tested under the coordinated program.

Arhar Coordinated Trial-2 (ACT-2)

This third group of trials (ACT-2) were formulated to accommodate varieties of up to 200 days maturity. In earlier years of testing, the ACT-2 consisted of nine varieties. In course of time some more entries of this group became available. Sharda and Mukta, developed at IARI, were released by the Central Varietal Release Committee for northeast, central, and peninsular regions. Because of the relatively warmer soil temperatures throughout the year, *Fusarium* wilt is a major limiting factor in these regions, and tolerance if not resistance, is an important requirement. These varieties appear tobt de, underfavorablemoistureconditions, to put out luxuriant growth, developing secondary and tertiary branching, and exploit the favorable environment optimally. The latest additions to this group of varieties under the coordinated program are BDN-1, BDN-2, AS 71-37, and JA-3.

Recently arhar breeders in the program have felt that the varieties presently included in ACT-2 group have too wide a range (160-200 days) of maturity and there is scope for splitting this trial further into medium (160-180 days) and mid-late maturity (180-210 days) groups. No. 148 and C-11, respectively, are the archetype varieties for the two groups. Varieties such as HY-1, HY-5, C-153, and C-159, which are at present tested in ACT-1, do not mature in time when tested at northern locations because of low temperatures in the latter part of the growth period. Such varieties will fit better into the medium-maturity group.

Arhar Coordinated Trial-3(ACT-3)

The final class, ACT-3, comprises the typical a rhars of north Ind ia. Sown with the onset of the monsoon in June-July, they continue up to March-April of the next year. These varieties are grown in rainfed areas mixed with jowar or bajra. After the harvest of the companion kharif crop in September-October, the arhar crop is allowed to continue, flourishing on the available soil moisture and tapping deeper and deeper layers of the soil for it. Late, tall, and bushy types, with very slow vegetative growth in the beginning and a capacity to fill up available space by extensive branching before the onset of the reproductive phase, give the best response (even up to 4 tonnes/ha) in such situations and land races have been evolved to meet these requirements.

Little directed plant breeding effort has gone into evolving better varieties in this group. Promising cultivars such as T-7, T-17, and Gwalior-3, developed about three decades back, are still holding the ground. As these are very late in maturity (300 days), they fit mostly in single-intensity, mixed-cropping situations under strict rainfed conditions, and the success of the crop is entirely dependent on rainfall distribution. In the northwestern plains, these varieties are mostly affected by frost. However, vast areas are still under such long-duration arhar varieties, and concerted efforts are needed for developing and testing varieties for this environmental niche.

To start with, the ACT-3 trial was evaluated under sole-crop conditions, though it was realized that the ideal situation for testing these varieties would be the mixed cropping situation prevailinginthe relevant area usingthe conventional companion crop of the region. Because of practical difficulties, however, this condition could not be realized until recently. In the 1978 kharif workshop, an ACT-3 set comprising 15 entries, with NP (WR)-15 and local checks, was developed, to be planted at 75 x 30 cm spacing, with one or two rows of intercrops conventional to the area *of* the concerned center.

Rabi Arhar Trials

September, or postrainy-season, sowing of arhar has already emerged as one of the exciting possibilities of fitting this crop into new farming systems in some parts of the country. Under such conditions, early- and medium-maturing varieties prove too early to give good yields, while the late varieties flower much earlier than usual, put on restricted vegetative growth and stand up to higher population pressure with good yields (Table 1). The archetypes for September-sown arhar were the late-maturing varieties Bahar and Basant of Bihar. As shown in Table 2, in the 1980 season a uniform set of 11 entries was put undertest for suitability for such a system at nine centers. Similarly, a set of five varieties is being tested for suitability for sowing in April, interplanted with mung. All the other trials will be sown also during the rabi season, while EACT will also be sown in November-December, after rice, in the eastern and southern states.

Outcome of the Coordinated Trials

A critical analysis of the evolution of coordinated trials at different stages reveals that the new material that has been recently built up, plus some still in the pipeline, has provided an array of useful genotypes. Study of varieties available before 1970 indicated that some of the already recommended varieties have good potential. An important outcome of the coordinated testing was that many of these varieties were shown to have good scope beyond the confines of the states or zones in which they were developed and released, for example, T-21, Pusa Ageti, Sharda, Mukta, No. 148, C-11, Gwalior-3, NP(WR)-15, T-7, and T-17.

A second review was done in 1975, when a pigeonpea working group at the annual kharif pulses workshop identified several new varieties that had performed well in coordinated trials. Prabhat, UPAS-120, and Pant A-3 were found superior in the EACT group; T-21, Pusa Ageti, BS-1, DL 74-1, and HY-1 in the ACT-1 group; No. 148, Mukta,C-11, JA-3and BDN-1in the ACT-2group;PS-41 and PS-65 were the new elite entries in the ACT-3 group, besides the varieties identified earlier.

An in-house review undertaken in 1976 indicated that no new material has come up in the EACT group; however, in 1977-78, several high-yielding varieties were entered under this program for multilocation testing. In ACT-1, TT entries from BARC, developed from T-21 through mutation, appeared promising because of increased seed size. Besides, HY-5, JA 9-19, and C-159 did well in the peninsular region; most of these new varieties have bolder seed size, which was lacking in the previous ACT-1 varieties.

In the ACT- 2group, no new variety outyielded the check (Mukta) in the northern plains, the east, and the central region. In the peninsular region, however, AS 71-37, BDN-2, and HY-3C did well. Results of the 1978 trials suggested that 4-84, DL74- 1,TT-5, CO-3, HY-1, and JA9-19 of the ACT-1 group outyielded the checks in different zones. In the ACT-3 group, particular mention may be made of variety Bahar, which was tested in September sowing in northern Bihar and gave very encouraging results.

Table 2. Pigeonpea trials conducted under the All india Cordinated Programme In 1980.

Category	No. Of entries	No. of locations*				Planting time	Plot size and row spacing	Remarks
		NPW	NPE	CZ	PZ			
EACT-1	13+ Local	15	4	4	2	July	5m x 2.4m 30cm x 10cm	
	13 + Local	1	6	3		Sept	5m x 2.4m 30cm x 10cm	Rabi pigeonpea
	13 + Local				5	Nov Dec	5m x 2.4m 30cm x 10cm	Rice fallows
ACT-1	14 + Local	8	4	6	10	July	5m x 4m 50cm x 20cm	
	14 + Local		3	1		Sept	5m x 4m 30cm x 10cm	Rabi pigeonpea
ACT-2	14 + Local	1	8	9	18	July	6m x 5m 75cm x 25cm	
	14 + Local		3		2	Sept	6m x 5m 60cm x 15cm	Rabi pigeonpea
ACT-3	12 + Local	3	6	8		July	5m x 6m 75cm x 30cm	
	12 + Local		4			Sept	5m x 6m 75cm x 30cm	Rabi pigeonpea
MLT-1	30		9			July		Early-maturing, Preliminary testing
MLT-2	23		5			July		Medium maturing
Rabi arhar	11		5			Sept		
April-sown pigeonpea + mung	4+1		6			Apr-May	8m x 5m 1n between rows	2 rows of mung to be sown between rows of pigeonpea

a. NPW = Northern Plains (West); NPE = Northern Plains (East); C2 = Central Zone; PZ = Peninsular Zone.

Other Aspects of the Program

The major burden of the Indian program has been to fit pigeonpea into as many niches in the country's farming systems as possible. In each maturity group, the process of testing and fitting in pigeonpea began with the recognition of a possible niche and the identification of an archetype variety that could fit that niche. Subsequently, newer and newer genotypes equally suitable for that niche streamed into the group. Table 2, showing the makeup of the different pigeonpea trials formulated in the 1980 kharif workshop, illustrates this well. The first criterion was, of course, the ability to fit the given agroecological limits; in addition, however, superiority in certain other aspects was built into these new genotypes: better fit to limiting parameters, less disease or pod-borer susceptibility, more acceptable seed size and quality, ability to withstand greater population pressure, and, in many cases, a measure of yield superiority. Both conventional breeding procedures and induced mutagenesis have been used in such work to achieve these objects. Some of the major aspects of such work in the Indian program are briefly summarized below.

Germplasm Collection, Classification, Evaluation, and Utilization

After its initiation, the All India Coordinated Improvement Project, in collaboration with the USAID, launched a countrywide, and to a limited extent, worldwide collection of genetic variability in pigeonpea. A total 5244 germplasm lines were maintained at IARI, New Delhi, and later at Andhra Pradesh Agricultural University (APAU), Hyderabad. A mimeographed catalog of these collections was published in 1969. Over 70% of them were from the important pigeonpea-growing states of Uttar Pradesh, Andhra Pradesh, Bihar, and Maharashtra. Less organized collections were made by the various centers of the Project also. In 1974-75, an intensive survey of Madhya Pradesh was done by the Jawaharial Nehru Krishi Viswa Vidyalaya (JNKVV) under an ad hoc scheme sponsored by ICAR, and over 800 samples were collected. Exchange of these collections between scientific teams at different centers was freely brought about. The entire collection available with the Indian program was also shared with ICRISAT when the latter was established.

Maintenance of germplasm in an often cross-pollinated crop such as pigeonpea is a very tedious job, and problems of contamination have been enormous. Indeed, a question may be pertinently raised as to what exactly should be regarded as a "germplasm line" in pigeonpea. It might well be argued that the best procedure would be to maintain landraces as populations. Obviously, practical problems, including those of the effect of unavoidable sampling on gene frequency, need attention. Considering these practical problems, it has been decided that germplasm collection under the coordinated program would be maintained in populations by bulking similar lines based on origin, maturity, plant type, seed quality, branching pattern, etc. Important genetic stocks to be used in the breeding program will be maintained separately as fixed lines, and pure seed will be produced every year by strict selfing, preferably by isolation.

Stabilization of Yields and Incorporation of Disease Resistance

Instability in performance is characteristic of all legume crops, including pigeonpea. Stability analyses carried out at the Coordinating Unit have amply demonstrated that genotypes of arhar (ACT-1 and ACT-2) differ in their linear regression on Environmental Index (*b* of Eberhart and Russel) as well as in the nonlinear deviation from such regression (s^2d of Eberhart and Russel 1966).

The preeminence of genetic resistance for economic disease control is well recognized. This is all the more true in the case of such low-return crops as pigeonpea.

Screening for wilt resistance in pigeonpea began even earlier than breeding/genetic studies. As a result of this pioneering work, McRae and Shaw (1932) were able to identify several "unit species" or types with substantial resistance to wilt. They were also able to establish a very high probability of the resistance being heritable, with no demonstrable association with morphological characteristics. The sources of resistance isolated by these pioneer workers have been used as the donors in later breeding schemes for incorporation of wilt resistance, leading to the development of resistant types such as NP (WR)-15 (Deshpande et al. 1963).

Screening for wilt resistance has continued to be a major concern of the Indian program. As a result, a number of sources of resistance have been identified (Table 3) and tested at several locations in National Uniform Disease Nurseries. As will be seen, some of the entries are from ICRISAT pathologists. An important point to be noted here is the indication of the possible existence of physiological races of the causal organism, *Fusarium udum.*

Stem blight caused by *Phytophthora* species was first identified by the pathologists of the Project. Subsequent screening of the gerplasm by pathologists has resulted in the identification of several resistance sources such as AS-3.

Of late, sterility mosaic has assumed serious proportions in some areas and some seasons. Screening methods developed by pulse pathologists at Pantnagar resulted in the identification of several genotypes resistant to the disease. Testing under the National Disease Nurseries Program has highlighted the possible

Table 3. Disease- and past-resistant plgaonpea lines Idantifiad at different canters in All India Coordinated Trials.

Disease-resistant lines	
Wilt resistant lines	
Jabalpur	BDN-1, BDN-2, 15-3-3, K-28, K-73, S-29, C-11, 20-1, Betul-10A, Gura-1, DL-74-1, Shivpuri-2, Bhind 6A, Pant A-1, Pant A-3
Indore	ICP-3783-3-1, ICP 7119-168-13, Hy-3C, ICP 6996-139-7, ICP 7035-34-5
Kanpur	K 4868, 22, AWR-74/15, KWR 1-1-91-1, AS-29, 3-1-A, Bon-1,T-17, T-70 and 73.
Delhi	Pant A-3 (3.3%), NP (WR)-15 (1.5%)
Coimbatore	Pant A-3 (0.6%), NP (WR)-15 (3.3%)
Sterility-mosaic-resistant lines	
Pantn agar	C-11, Hy-3A, Hy-3C, Pant A-2, 8, 76, 77, ICRISAT lines 3783, 6997, 7035
Phytophthora-blight -resistant lines	
Delhi	BDN-1, A-57, As 3/77, P 19-1, P 41-2/1, P-808, P-858, P-3136, P-3624, P-1135
Root-rot-resistant lines	
Coimbatore	Co-2, Co-3
Gulbarga	JA 9-19
Madurai	Co-2, BR-172, DL 74-1, Pant A-3
Pest-resistant lines	
Lines with some degree of pod-borer resistance	
Hyderabad	4460, 3757, 2377, 2725, 2942/1
Ludhiana	H-111,114, L-14
Madurai	109427, 7035, 76-64-2, TT 3/3, 2742, TT-2/11, 6909, Pant A-2

existence of biotypes of the virus and/or the vector mite. As is to be expected, the intensification of pathological investigations as well as extension of pigeonpea cultivation has thrown up new problems. One such is *Alternaria* blight of September-sown arhar in some seasons. Sterility mosaic in an intensive form has also been reported in rabi-sown crops.

Seed Quality

Three types of quality characteristics are involved in the utilization of pigeonpea: aesthetic, processing, and nutritional. Little attention has been paid so fartothe first and third; somework has been done on processing quality. Increasing seed size has been a major objective, particularly in the EACTand ACT-1 groups. This has been achieved to some extent, and most of the entries currently under test in this group (Table 2) are improvements in seed size. Conventional breeding methods, including the use of bold-seeded vegetable types, as well as mutation breeding have been utilized.

The basis of the market premium for larger seed may partially be the better recovery obtained during the milling process. Studies have been carried out in cooperation with the Central Food Technological Research Institute (CFTRI), Mysore, to determine whether there could be a varietal component to such behavior. There is evidence for such varietal differences under the improved milling techniques developed at the CFTRI.

The range (18-26%) fortotal protein content, has been relatively narrow (Swaminathan and Jain 1972); however, as much as 32% protein has been reported. Recent analysis of protein content dhal recovery and cooking time in a set of varieties grown at different locations, showed the presence of considerable G x E interaction (Table 4).

Breading for Productivity

The last, and most important, objective has been breeding for better productivity. Considerable efforts have gone into this, using mostly conventional breeding programs. Other pathways being explored are heterosis breeding and crosses between divergent germ plasm. Genixc male sterility has been reported earlier in pigeonpea and recently from ICRISAT. It must be noted that ICRISAT hybrids produced using this male sterility, which were tested in the Indian program, have not shown much superiority (Table 5) over existing elitecultivars. Such testing, however, has not yet been very exhaustive. The sterility is also being transferred to different genetic backgrounds.

Conclusions

In conclusion, it might be useful to indicate the broad lines of the current pigeonpea improvement program in India:

Table 4. Pooled analysis of protein percent, milling quality, and cooking time of seven varieties of pigeonpea grown at seven locations in India, 1978—79.

	Location						
Variety	Dantiwada	Nowgaon	Nayagarh	Junagarh	Baroda	Akola	Delhi
			Protein content (%)				
TT-4	20.4	21.1	20.4	20.1	21.4	20.3	19.4
4-84	20.3	21.1	19.7	20.4	19.2	18.8	20.6
4-64	21.1	21.4	21.9	19.7	19.1	19.2	20.2
DL-74-1	20.8	21.7	18.9	20.1	19.1	19.1	21.2
TT-5	20.6	20.9	20.3	20.3	19.1	21.7	21.4
TT-6	19.5	22.6	19.4	20.9	20.3	19.9	19.8
TT-2	19.9	22.2	19.1	20.3	19.1	18.9	19.7
			Milling (%)				
TT-4	83.4	85.7	83.1	82.5	82.9	82.8	84.7
4-84	82.2	86.1	83.2	83.9	83.9	84.7	80.8
4-64	80.2	85.6	84.2	82.3	83.9	83.3	85.0
DL-74-1	82.5	86.1	84.6	83.3	84.5	83.9	85.9
TT-5	82.4	86.1	83.9	81.6	83.6	83.1	85.7
TT-6	818	86.4	85.6	83.5	83.4	84.2	85.5
TT-2	82.1	86.0	83.4	80.6	83.9	83.9	85.8
			Cooking time (minutes)				
TT-4	20	21	21	18	20	17	19
4-84	20	21	21	19	18	16	20
4-64	21	21	21	19	18	18	21
DL-74-1	22	21	21	19	20	18	21
TT-5	22	21	20	19	19	18	20
TT-6	21	21	21	18	19	18	20
TT-2	21	20	22	18	18	18	19

Proterin content Location LSD (1%) = 0.44; Varieties LSD (1%) = 0.44; L x v LSD (1%) - 1.17.
Milling *{%)* Location LSD (1%) = 0.42; Varieties LSD (1%) - 0.42; L x V LSD (1%) - 1.1.
Cooking time Location LSD (1%) = 0.56; Varieties LSD (1%) -0.56; L x V LSD (1%)- 1.47.

Table 5. Relative performance of pigeonpea hybrids (ICPH No.) in ACT-2 (1979-80) compared with high yielding cultivars.

Variety	Grain yield (kg/ha)	Maturity (days)	LSD of Trial (kg/ha)
	Varanasi		
Lam RG-30	1516	195	373.00
Lam RG-36	1413	198	
GS-1	1258	195	
c-11	1231	195	
ICPH-1	1143	195	
	Baroda		
B-12	2132	168	417.00
Lam RG-30	1981	174	
T-15-15	1926	176	
GS-1	1779	180	
ICPH-1	1125	178	
	Junagarh		
Lam RG-30	644	162	NS
ICPL-42	600	159	
BDN-2	575	126	
ICPH-1	542	150	
T-15-15	538	126	
	Gulbarga		
C-28	733	194	NS
BON-2	676	207	
ICPL-43	641	213	
ICPL-42	633	213	
ICPH-2	605	203	
ICPH-4	307	209	

1. The major approach will continue to emphasize developing genotypes suitable for specific agroecological niches. Within this constraint, emphasis will be on seed yield and processing qualities and yield superiority.
2. A keenly felt need is to endow the crop with a certain degree of stability. Genotypes will therefore be evaluated for their adaptability as measured by their linear and nonlinear responses to the complex of uncontrollable environmental factors. Incorporation of disease resistance, particularly multiple-disease resistance, will be stressed. The possibility of exploiting genetic resistance to some of the important insect pests will be further explored.
3. Efforts to understand how a quantum jump can be obtained in the productivity of the crop—including physiological analyses, biometrical analyses, exploitation of genetic divergence and heterosis, and studies on the *host-Rhizobium* complex — will continue.

References

DESHPANDE, R. B., JESWANI, L. M., and JOSHI, A. B. 1963. Breeding of wilt resistant varieties of pigeonpea. Indian Journal of Genetics 23: 58-63.

EBERHART, S. A., and RUSSEL, W. A. 1966. Stability parameters for comparing varieties. Crop Science 6: 36-40.

MAHTA, D. N., and DAVE, B. B. 1931. Studies in *Cajanus indicus.* Memoir, Department of Agriculture, India (Bot. Ser.) 19: 1-25.

MCRAE, W., and SHAW, F. J. F. 1932. Influence of manure on the wilt disease of *Cajanus indicus* Spreng. and the isolation of types resistant to the disease. Part II. The isolation of resistant types. Imperial Council of Agricultural Research Science Monograph 7, Delhi, India.

PATHAK, G. N. 1970. The red gram. Pages 14-53 *in* Pulse crops of india (ed. P. Kachroo). New Delhi, India: ICAR.

RAMANUJAM, S., and SINGH, S. P. 1977. Role of elite varieties of pulse crops in increased pulse production. Pages 61-65 *in* Pulse development souvenir, Directorate of Pulse Development, Lucknow, Uttar Pradesh, India.

SHAW, F. J. F.,KHAN, A. R., and SINGH, H. 1933. Studies in Indian pulses. 3. The types of *Cajanus indicus* Spreng. Indian Journal of Agricultural Science 3: 1-36.

SWAMINATHAN, M. S., and JAIN, H. K. 1972. Food legumes in India's agriculture. Presented at the FAO Symposium on Nutritional Improvement of Food Legumes by Breeding. PAG (FAO), 3-5 July 1972, Rome, Italy.

Pigeonpea Breeding in the Caribbean Regional Programme

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Abstract

Three pigeonpea production systems exist in the Caribbean region: (1) full-season crop production practiced by the small farmers, (2) mechanized large-scale production in which high crop density is used, and (3) dry grain production under high crop density. Segregating populations originating from ICRISAT are screened for adaptability, with the aim of improving full-season crop production and dry grain production. With respect to high-density cropping, daylengthltemperature-insensitive germplasm would be ideal, since the number of days taken to flower also influences plant height. Research in progress for the breeding of insensitivity to daylength and temperature and a proposal for using solar heat and extended light period as a means of screening for insensitivity are discussed.

The Caribbean region, in the context of pigeonpea production and consumption, may be considered as including not only the chain of islands that extend from Trinidad in the south to Jamaica and Cuba in the north, but also Central and South American countries where the crop is a significant food legume. The location and environmental features of the islands have been described by Ariyanayagam (1975) and these in general apply to the pigeonpea-growing areas of Central and South America. A common denominator for both groups is that pigeonpea is consumed in the fresh green vegetable form, in contrast to India, where the preference is for the dry split or whole seed. Furthergenotypic requirementsand production techniques are similar in the two groups of countries.

In terms of total production of the crop the Dominican Republic, Haiti, Panama, and Jamaica are the major producers in the region. About 20 other smaller countries produce substantial amounts of the crop and for all of them pigeonpea is the best adapted grain legume. Considerable potential exists for expanding pigeonpea cultivation in some of these countries, e.g., Guyana and Belize.

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The specific consumer preference mentioned earlier imposes severe limitations on the supply and demand status of green peas, since daylength and temperature effects permit flowering and fruiting of the local germplasm in only 2 to 3 months of the year. Consequently demand always outstrips supply.

Overall objectives of the Breeding Program

The first objective of the University's breeding program is to enhance the supply situation, through alteration of the reproductive behavior of the crop so as to achieve year-round production. Realization of this aim will, it is anticipated, lead to changes in the cropping pattern along lines proposed by Spence and Williams (1972). Such changes may not be readily accepted by small farmers who favor the traditional full-season crop (Ariyanayagam 1975) that contributes a major share to the total production. Hence another objective of the University's program is related to their specific needs. In recent years dry grain production as practiced outside the region has been attempted with considerable success in two countries, Barbados and Guyana. This system has several advantages and scope exists for its expansion.

Therefore the third major objective is to identify suitable dry grain types for the region.

Progress to Date

Full-season Crop

The strategy with respect to breeding full-season crop and dry grain types, is straight selection for adaptability, desirable pod characteristics, and possibly, ease of harvesting characters that might make harvesting less burdensome. Segregating populations provided by ICRISAT, and some introductions have shown promise as source populations for the type of germplasm the West Indian small grower would desire. Among several source populations screened so far, a few families derived from the crosses 6914 x 7035 and 3043 (PA x JA-276) are due for regional evaluation shortly. The green pea size and pod characteristics of some of the families appear superior to the local selections under Trinidad conditions. Their dry-grain weight exceeds 12 g/100 grains. Pods are mostly concentrated terminally at the ends of branches, a feature that should facilitate manual harvesting. This operation currently accounts for 70% of production costs.

A second group of families derived from the crosses EC-107654 x T-21 and EC-107657 x T-21 are determinate, and produce 5- to 6-locule pods. Their dry grains weigh over 12 g/100 grains. They flower in 75 to 90 days in the off-season planting (January) and 100 to 110 days after the regular planting in May-June. This group may also contain genotypes suitable for mechanical harvesting and probably dry grain production as well.

Year-round Production

Pedigree selection for earliness, determinate habit, and green pea size, was done at different times of the year under natural daylength and temperature and this resulted in two families with acceptable characteristics. These were derived from crosses (1 x 88) and (5 x 20). Parent 1 in the first cross and 20 in the latter are of West Indian origin, while 8 and 5 are introductions from IITA, Nigeria, and Uttar Pradesh, India, respectively. The line derived from the first cross is designated UW-17, and the latter UW-26.

Flowering Times

The flowering response of the two lines to planting times was evaluated in Jamaica, Trinidad, and Guyana. The respective daylengths at these locations are 12.2 to 13.4 hours, 11.5 to 12.7 hours, and 11.8 to 12.2 hours. In Jamaica, 50% flowering for UW-17 varied from 60 to 75 days and the range for UW-26 was 62 to 82 days (Table 1). As daylength increased from February to June, anthesis was delayed in both genotypes. The trend in Trinidad was somewhat similar to that in Jamaica (Table 1) although the range was larger — 21 days for UW-17 and 25 days for UW-26. In Guyana,

Table 1. Number of days from sowing to flowering for dlfferent pigeonpea plantings In Trinidad and Jamaica.

	Days to flower			
	UW-17		UW-26	
Month	Trinidad	Jamaica	Trinidad	Jamaica
January	65	69	70	79
February	66	71	72	78
March	69	71	77	77
April	81		88	
May	86	74	95	75
June	85		90	
July	76	75	82	
August	79		81	
September	80	65	78	
October	72	62	77	
November	70	60	72	
December	69		73	62

planting time did not greatly influence flower initiation. In all cases flowering occurred in 65 to 70 days (J. Dummett, personal communication). Thus flower initiation per se is unaffected for the 2 genotypes between Jamaica (latitude 18°2' N) and Guyana (latitude 4°N).

However, the number of days taken to flower varied with planting date. The differences, in fact, are not as large as those shown by West Indian germplasm when grown under similar conditions. Yet they are large enough to cause marked variation in preflowering vegetative growth, which in turn influences the canopy structure for the different planting dates. The consequences of such changes for agronomic practices such as stand density, pest control, and harvesting need no elaboration.

Preflowering Vegetative Growth

The influence of planting date on preflowering vegetative growth at Jamaica and Trinidad is shown in Figure 1. The height of UW-17 for the former location ranged from 117.5 cm for the May planting to 35 cm for the November planting. In Trinidad the June planting was taller by approximately 50% than the January planting. Branching in both locations was profuse in plantings done during lengthening days. In Guyana, plant height was not much influenced by planting date. Obviously, when growth differences of the magnitude noticed in Jamaica and Trinidad occur for the different planting dates, the same density of planting cannot be expected to be equally productive at all times.

On the basis of these observations, five genotypes, (1x88)-3; (5x20)-10; (61x17)-9; (1x88)-10; and (1x88) (48 x 1)- 1 which appeared day-neutral under natural long-day conditions in Trinidad were investigated along with Chaguaramas Pearl, a sensitive genotype, for their responses to the photoperiod/night temperature regimes shown in Table 2.

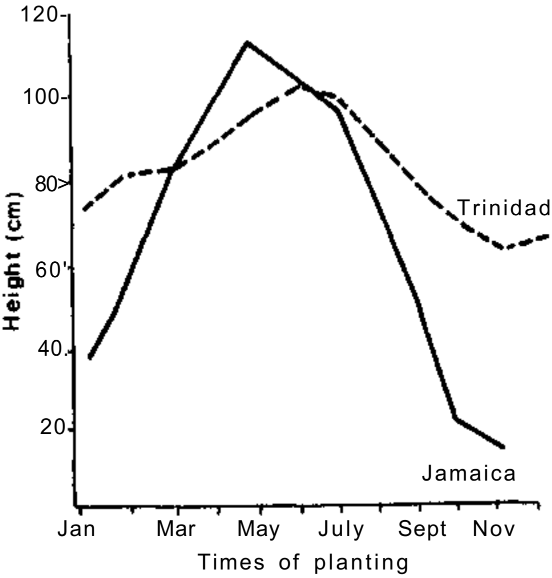

Figure 1. Mean plant height of UW-17 in Jamaica and Trinidad.

Table 2. Photoperlod/night-temperature traatmanta for five plgaonpaa genotypes.

No.	Photoperiod	Night-temperature
1	11 h, natural light + 1 h, artificial light	18.3°C
2	11 h, natural light + 1 h, artificial light	28.9°C
3	11 h, natural light + 3 h, artificial light	18.3°C
4	11 h, natural light+ 3 h, artificial light	28.9X
5	11.5 natural daylight to 12.5 h (Mean 11.83 h.)	16.1°C to 23.9°C (Mean 21.7°C)

Plant Height

Table 3 shows the plant heights recorded at flowering. All cultivars showed similar growth trends, being shortest under short day/low night temperature (12 h/18.3°C) and tallest under long day/high night temperature (14 h/28.9°C). Cooler nights within each photoperiod treatment produced shorter plants. In the ambient light and temperature between 12 h/18.3°C and 12 h/28.9°C, all genotypes were of intermediate height.

It is clear that neither photoperiod nor night temperature per se influences height. If photoperiod alone is assumed to be responsible, insignificant variation would be expected between the two night-temperature regimes within each photoperiod. On the other hand, if the assumption is that night temperature alone influences plant height, then each genotype in the lower night temperature under the two photoperiods should have attained similar height and this would have been trueforthetwo higher night temperatures as well. The data, however, indicate that plant height is not influenced by any single factor, but by the interaction of both.

Varietal differences within treatments are clearly seen, but from a practical point of view insignificant differences between treatments are more important None of the genotypes tested showed such a trend. (61 x 17) - 9 is probably not as greatly affected by photoperiod/temperature effects as the rest of the genotypes.

Days to Flower

The number of days taken to flower shown in Table 4 follows the same trend as plant height. Among the photoperiod-temperature combinations investigated, the short-day, lower night-temperature treatment hastened flowering, while the long-day warmer night temperature produced the opposite effect. (61 x 17) -9 was least influenced by photoperiod x temperature effects, the difference being negligible within each light period and the variation being 9 days between the short day lower temperature and long day warmer temperature. This study suggests that insensitive genotypes may exist among the pigeonpea germplasm collection.

Field observations in the West Indies suggest that day temperature may indeed influence flowering and vegetative growth as much as night temperature and daylength. Further, many soybean *(Glycine max)* varieties, like pigeonpea, were found (Summerfield 1976) to exhibit delayed flowering in the longer days but, unlike pigeonpea, the sensitive varieties flowered up to 20 days sooner in warmer nights (23.8°C). With cowpea *(Vigna unguiculata),* plants grown in warmer nights flowered 5 to 27 days earlier (Summerfield 1975). Hence, in soybean and cowpea, the effects of longer daylength in delaying flowering and of the warmer nights in hastening it were found to almost exactly offset one another. As a result, the difference in time to first flower under the extreme treatment conditions of the experiment was no more than 2 days (Summerfield 1975,1976). Inthe case of pigeonpea, sinceboth long days and warm nights tend to delay flowering, the combined effect of both factors on genotypes that are apparently day-neutral is to

Table 3. Plant height of pigeonpea genotypes exposed to varying daylength and night temperature environments.

	Plant height at				
	Daylength 12 h. night temp.		Daylength 14 h. night temp.		Ambient daylength/ night temp.
Genotype	18.3°C	28.9°C	18.3X	28.9°C	
(1x88)-3	57.3	99.6	114.8	154.8	96.9
(5x20)-10	82.3	111.5	141.0	148.5	110.0
(61 x 17)-9	88.5	125.1	142.6	154.8	110.2
(1x88)-10	70.5	117.7	149.5	151.8	116.4
(1x88) (48x1)-1	87.4	122.5	146.0	158.3	114.8
Chaguaramas pearl	126.4	130.3	182.4	186.7	143.5

Table 4. Mean number of days to flower in different daylength/night temperature environments.

	Days to flower (mean)				
	Daylength 12 h. night temp.		Daylength 14 h. night temp.		Ambient daylength/ night temp.
Genotype	18.3°C	28.9°C	18.3°C	28.9°C	
(1x88)-3	52.8	65.0	71.8	101.0	68.8
(5x20)-10	61.8	63.2	75.5	80.5	72.2
(61 x 17)-9	65.5	65.8	72.8	74.8	65.8
(1x88)-2	58.6	67.5	77.2	103.5	70.8
(1x88)(48x1)-1	60.8	68.8	76.8	80.2	74.0
Chaguaramas pearl	77.2	81.8	117.2	N.F.	96.8

delay flowering by 9 to 48 days. The sensitive genotypes, on the other hand, may notflower at all under similar environmental conditions. Figure 2 summarizes these responses for the three crops.

Work in Progress

Full-season and Dry Grain Crops

In addition to the genetic material already men-

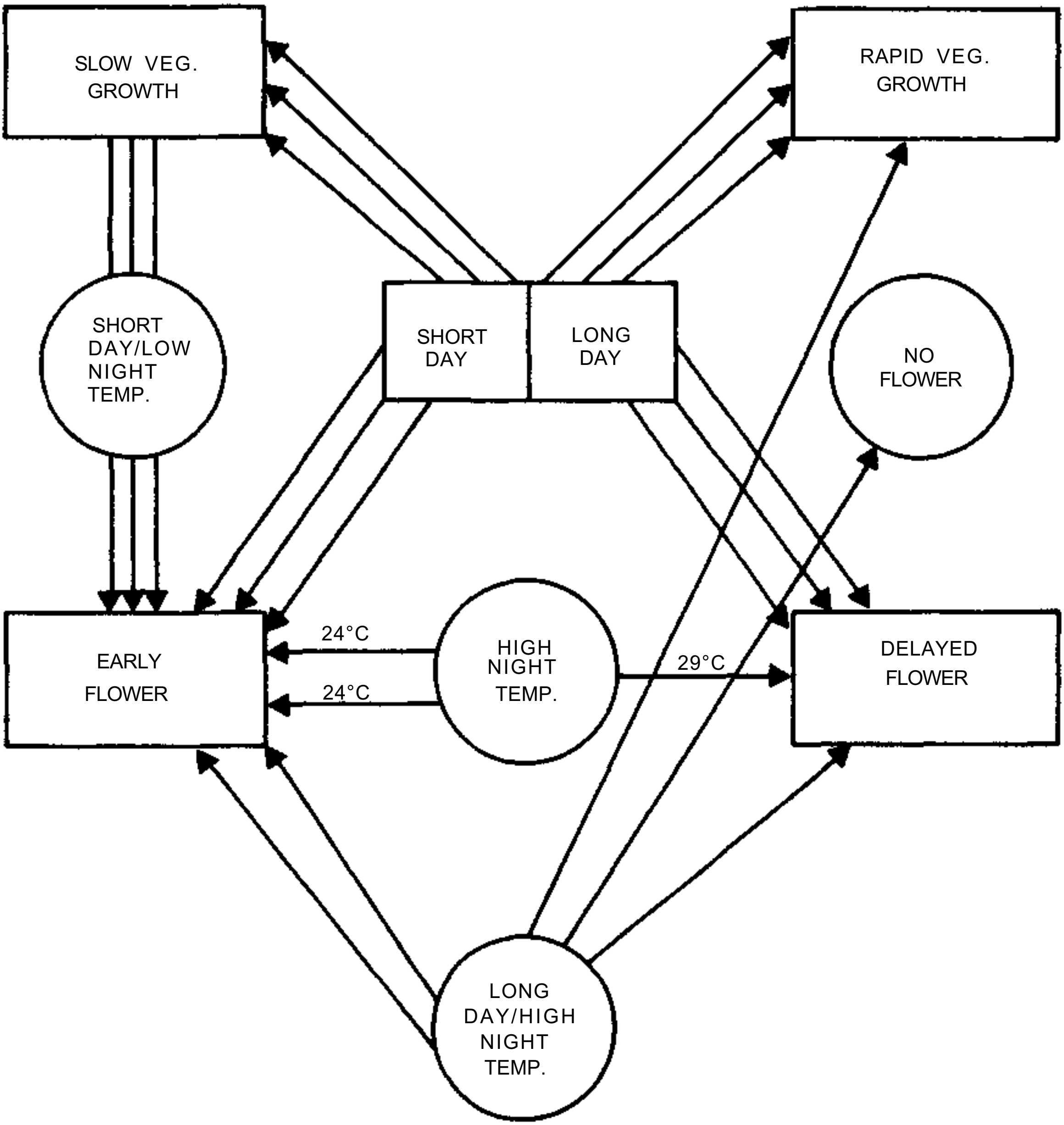

Figure 2. Day lengthlnight temperature effects on vegetative growth and flower induction in pigeonpea, cowpea, and soybean.

tioned, a few other types also originating from ICRISAT are being screened in a similar manner. Additionally, the International Vegetable Pigeonpea Trials, and newer populations bred at ICRISAT will be examined on a continuing basis.

Year-round Cropping

The main limitation to year-round cropping is neither the inability to obtain floral induction in any period of the year, nor the difficulty of incorporating characteristics such as large pods, peas, determinate habit, etc. The main limitation is finding low between-season variability for preflowering vegetative growth. Screening methods for identifying such variability do not exist. Nonetheless, as a short-term measure, improvement of characters other than preflowering vegetative growth is being attempted. Work is now in progress on this.

Pea and Pod Characteristics

The early-flowering genotypes UW-17 and UW-26 bear medium-length pods consisting of five to six locules. Peas are of medium size when green; when mature and dry they weigh 6 to 9 grams/100 grains. The consumer prefers larger pods and peas, characteristics of parents such as IC-7035, IC-6997, UWI-303 and UWI-297. Such parents are being combined with UW-17, UW-26, early-flowering introductions from Australia, and other lines developed in our program. These are being combined via pedigree as well as recurrent selection procedures.

Some populations developed at ICRISAT using 7035 or 6997 as one of the parents have shown very acceptable pea size, though pods are of medium length. Selection is continuing in a few of them for the former character.

Earliness to Flower Versus Large Peas and Pods

During the initial phase of the program, the early-flowering character appeared to be partially linked to small pods and peas. Hence recurrent selection for large pods and peas among early-flowering populations and selective mating are being attempted. Promising lines, as far as these two characteristics are concerned, are emerging. Preflowering vegetative growth, however, continues to be erratic.

Selection for Seed Size

Selection for seed size is confusing due to variability both between and within seasons. Table 5 shows heritability estimates obtained in Trinidad using progeny-parent regression as the estimator. The parents and progeny in this study were grown in similar seasons (Jan-Apr) of different years. In all cases, the values are low and in general agreement with those found at ICRISAT (Table 5), where the parents and progeny were grown in the same year but different seasons. Keatinge (1980) further found highly variable 100-grain weights in 21 out of a set of 24 cultivars grown in soil-moisture stressed and unstressed conditions in the same growing season. Seed weight of most legumes on the other hand, particularly kidney bean, pea, soybean, and chickpea, are reported (Sinha 1977) as not much influenced by environmental conditions. Pigeonpea therefore seems an exception with respect to this trait.

Yield of Peas and Pods

Yield of peas has been reported as being dependent on pod number per plant (Munoz and Abrams 1971; Joshi 1973). Keatinge's study (1980) suggests that the number of pods per plant is reduced under moisture stress condi-

Table 5. Heritability estimates for 100-graln weight based on progeny-parent regression.

	Heritability percentage				
Location	$h^2=b$	$h^2 = b/2rxy$	$h^2 = 2b/3$	$h^2 = b$	$h^2=2b/3$
University of the West Indies	42.0	33.8	28.0	19.0	12.6
ICRISAT Center	31.3	38.0	21.0	40.6	27.1

tions, confirming the findings in other legumes, where pod number and seed number were influenced adversely by similar stress situations (Sinha 1977).

Pod number in pigeonpea is probably also affected by the growing season, plant type, maturity range, and abscission of reproductive structures. A preliminary estimation of per plant pod yield was done, taking into consideration these factors.

Indeterminate and determinate planttypes of similar maturity range were studied in the field during the Jan-Apr season of 1976 and 1977. Different cultivars of the two plant types were studied each year. The procedure consisted of sketching, approximately to scale, all flowering branches in each plant and, on alternate days all through the reproductive phase, making a color-coded record of events such as the appearance of buds, abscission of buds, anthesis, abscission of flowers, pod formation and abscission, and,finally, pods attaining maturity. This procedure permits an accurate assessment of buds initiated, abscissed, or retained on each branch of a plant and over the whole plant at 48-hour intervals, all through the reproductive phase. Tables 6 and 7 contain a summary of the data for the two plant types. In the case of the indeterminate plants, even though genotypes involved in the 2 years were not the same, and the numbers of buds initiated were considerably different, the percentage of buds producing mature pods was approximately equal, i.e., 12.1% and 12.5%. The determinate plants sup-

Table B. Abscission of reproductive structures in indeterminate pigeonpea.

	Reproductive Structures (mean)						
	Buds/Plant		Flowers/Plant		Pods/Plant		
Year	Initiated	Abscised	Formed	Abscised	Formed	Abscised	Retained
1976	942	303 32.2%[a]	639	366 57.3%[b] 38.9%*	273	159 58.2%[b] 16.9%[a]	114 12.1%[a]
1977	1080	454 42.0%[a]	626	282 45.0%[b] 26.1%[a]	345	210 60.9%* 19.4%[8]	135 12.5%[a]

a. Expressed as percentage of buds initiated.
b. Expressed as percentage of flowers on pods formed.

Table 7. Abscission of reproductive structures in determinate pigeonpea.

	Reproductive Structures (mean)						
	Buds/Plant		Flowers/Plant		Pods/Plant		
Year	Initiated	Abscised	Formed	Abscised	Formed	Abscised	Retained
1976	870	387 44.5%*	483	269 55.7%[b] 30.9%[a]	214	92 43.0%* 10.6%*	122 14.0%*
1977	675	990 14.7%[a]	576	350 60.8%* 51.9%*	226	111 49.1%* 16.4%*	115 17.3%[a]

a. Expressed as percentage of buds initiated.
b. Expressed as percentage of flowers or pods formed.

ported a slightly higher percentage of pods at maturity in both years and the difference between years was 3%. Despite this small discrepancy, this preliminary study suggests that given the same length of growing period, both determinate and indeterminate plant types support only 12 to 17% of the total number of buds initiated until they mature into pods. In terms of numbers of pods per plant, the differences are again small between, as well as within, plant types for the 2 years.

Abscission in both plant types was heavy in the flower and pod stages. The indeterminate plants aborted 57.3% and 45.0% of the flowers formed in 1976 and 1977 respectively. If abscission at the flower stage is considered as a percentage of the buds initiated the respective figures for the 2 years are 38.9% and 26.1%. The comparative figures for the determinate plants were 55.7% in 1976 and 60.8% in 1977, for the former and in the latter instance 30.9% and 51.9% respectively for the 2 years.

Interestingly, more than half (58.2% and 60.9%) the number of pods formed are shed by the indeterminate, while almost half (43.0% and 49.1%) are dropped by the determinate type. Considering these numbers as a percentage of the buds initiated, the indeterminate types shed 4.8% and 6.9% respectively, in excess of the pods retained. In the determinate, on the other hand, pods retained exceeded the abscissed by 3.4% and 0.6% for the 2 years. The question arises as to why abscission should occur to such a large extent so late in the reproductive phase, after pod formation. Could this be related to the perennial habit of the crop? Intensive research in this area might be the answer for a substantial breakthrough in pod number increase and eventually grain yield improvement.

Long-term Plan

The long-term objective is to seek low variability for preflowering vegetative growth, which, as pointed out earlier, is the main limitation to year-round cultivation of pigeonpea in the West Indies. Towards this end four projects are in progress.

Use of Dwarfing Genes

Three dwarf genotypes have been identified and described by ICRISAT in their Pigeonpea breeding annual report, 1976-77. In addition, two others have recently been found at the University of the West Indies. One of them appeared among an Fa population of a cross between Atylosia *sericea* and UW-26. This, like the dwarf Do found at ICRISAT, has very compact internodes, but is probably more sensitive to daylength x temperature interactions. In order to distinguish it from Do, it has been designated ADO.

The second appeared in an F_4 population of a double cross involving early-flowering parents and large-seeded parents. Unlike any of the dwarfs identified at ICRISAT, it has firm, fibrous stems and appears normal except for the smaller leaves, larger number of nodes, and compressed internodes. It is also less sensitive to daylength and temperature effects as compared with D_1 and D_2. In 14 hours light and a uniform temperature of 35°C during day and night A_{D1} maintained the dwarf characteristics, but flowering was delayed as compared with ambient conditions. Investigations on its responses as well as those of the other dwarfs to daylength-temperature interactions are being done, since dwarfing genes may be a means of minimizing the variable preflowering vegetative growth induced by environmental changes.

Wide Crosses

Ariyanayagam and Spence (1978) reported that *Atylosia platycarpa* might be a suitable gene source for insensitivity to daylength and temperature. Progeny of what appear to be A *platycarpa* x *Cajanus* crosses however, have always resembled A *platycarpa,* and segregation has not been noticed even at the F_4 stage. Recently, evidence of a high degree of cleistogamy in A *platycarpa* has been obtained, and further investigations are in progress. It is also likely that apomictic development occurs in this case, giving the impression of success when crossed with *Cajanus.* Interest in A *platycarpa* continues, since viable F_1 plants have been recovered recently from crosses with pigeonpea-like plants obtained from an F_3 population of another wide cross involving A *sericea* and UW-26.

Atylosia sericea is a highly daylength-sensitive species, which, if planted in January in

Trinidad will not flower until November or December. During this long vegetative growth period its height, interestingly, does not exceed 1 to 1.3 m. A sensitive pigeonpea such as 7035 or UWI-303 during the same period will attain a height of 2.5 m to 3 m. A *sericea* further produces a large number of nodes that are potential flowering sites.

Table 8 shows the plant height, node number, and internode length of *A. sericea* and Code 1 in three environments, namely, ambient conditions, high air temperature + 14 hour light period, and low air temperature + 14 hour light period. The data were recorded at monthly intervals, commencing 1 month after planting. Plant height of Code 1 in each month and in each of the three environments was substantially more than of A *sericea.* More importantly, height variation between treatments for each month was greater in Code 1.

In this experiment, the air temperature in treatment 3 often exceeded 40°C, a situation rarely met with in areas where the crop is grown commercially. The other two treatments were nearer reality, and the height differences for A *sericea* between them were much narrower than for Code 1.

Table 8 further shows that A *sericea* produces many more nodes than Code 1 as it increases in height and that the internode length is not as greatly increased, particularly in treatments 1 and 2. The growth patterns of the two plants are hence different. If these features of A *sericea* were incorporated into pigeonpea. the vegetative growth of the latter might be restrained within manageable limits.

Screening for Daylength/ Temperature Effects

Previous work (Ali and Ariyanayagam 1979) demonstrated that screening under long-day environment alone or a single daylength/ temperature environment is not an effective means for identifying genotypes insensitive to daylength/temperature effects. Hence a screening procedure that would permit comparison of vegetative growth and floral induction between environments is being investigated.

Four temperature/daylength environments were generated, using solar energy to raise air temperature around the plants and supplemental light emitted by three 100-w incandescent lamps over a 1- to 2-hour period, commencing $^1/_2$ hr before sunset:

1. High temperature +13 to 14 h light (HT+LD)
2. Low temperature +13 to 14 h light (LT+LD)
3. Ambient temperature +13 to 14 h light (AT+LD)
4. Ambient temperature and natural light (AT+NL)

The high and low temperature effects were produced within shelters measuring 3m x 3m x 2m. The roof of each shelter was covered with clear polyethylene flexible sheets. The high-temperature effect was generated by

Table 8. Plant height, numbar of nodes, and internoda length of Coda 1 and *A.* sericea grown in three environments.

	Plant height (cm)			Number of nodes			Internode length (cm)		
Date/Genotype	1	2	3	1	2	3	1	2	3
29 Apr 1980									
A. sericea	6.4	8.3	11.6	8	13	11	0.8	0.6	1.1
Code 1	16.3	28.5	44.2	8.3	10	14	2.0	2.9	3.2
27 May 1980									
A. sericea	32.7	43.5	79.5	63	74	75	0.5	0.6	1.1
Code 1	45.5	85.5	171.3	2.5	33	48	1.8	2.6	3.6
16 June 1980									
A. sericea	46.6	59.0	140.0	84	96	142	0.5	0.6	1.0
Code 1	64.5	114.3	203.7	33.5	44	58	1.9	2.6	3.5

1 = Ambient conditions; 2 = Low air temperature + 14 h light; 3 = High air temperature + 14 h light.

covering the four sides and the roof with the polyethylene material, while a lower temperature resulted from partial covering of two sides. The air temperature in these houses followed the fluctuating ambient temperature pattern each day, but at higher levels. The cumulative thermal units above a base of 15°C during the daylight hours were: high temperature 9760.4; low temperature 8059.6; ambient conditions 7596.4. The minimum nighttemperature in both shelters was lower than the minimum in ambient condition, but in all three treatments, the minimum night temperature was close to the high temperature used in the experiment by Ali and Ariyanayagam (1979). This temperature was shown to delay flowering while promoting vegetative development.

Seven cultivars, UW-17, E-18, E-49, T3-42, 34T-1, IC-28, and Code 1 were grown in single rows, 2.5 m long, in each of the four environments. The distance between rows and between plants in the row was 25 cm. Code 1 is considered sensitive to natural daylength/temperature changes, IC-28 partially sensitive, and the other five are insensitive. Commencing 1 month after the planting date, 30 Mar 1980, measurements were recorded at weekly intervals of the plant height, number of nodes, internode length, and number of leaves per plant. The final plant height and flowering responses are discussed here.

Days to Flower

The flowering response of the seven genotypes in each of the four treatments is shown in Table 9. Under ambient conditions of temperature and daylength, all the varieties considered as insensitive flowered in the expected length of time. Flowering was profuse and the plants appeared normal. IC-28 and Code 1 had not flowered when the experiment ended on 20 June 1980.

These two varieties did not flower in the rest of the treatments either. Code 1 being a sensitive variety normally does not flower until the onset of short-day conditions in November, if planted between mid-January and May. IC-28 is less sensitive than Code 1, but its flowering behavior is unpredictable for plantings done between February and May.

Extending the light period in ambient temperature (AT + LD) prolonged the length of time for flower induction in the other five cultivars. Further, flowering was scanty in UW-17. If extended light period alone is employed for screening as presently done, these five cultivars, having flowered not much later than in ambient temperature and natural light (AT + NL), would appear photoperiod insensitive. But as seen in column 2, Table 9, where they were subjected to a slightly higher temperature during the day, E-49 and E-18 failed to flower until the termination date. The other three cultivars flowered slightly later than in ambient temperature and extended light treatment, but flowering was very scanty in all cases. UW-17 further shed most of its flowers. Thus, the addition of temperature to daylength changes the entire concept of the flowering times in pigeonpea. Under high temperatures coupled with extended light period, none of the cultivars flowered.

Table 9. Number of days to flower of seven pigeonpea genotypes in four daylength/temperature environments.

Genotype	Days to flower			
	HT + LD	LT + LD	AT + LD	AT + NL
UW-17	nf	72*	68*	63
IC-28	nf	nf	nf	nf
E-49	nf	nf	74	59
T3-42	nf	67[a]	65	50
34T-1	nf	66"	61	50
Code 1	nf	nf	nf	nf
E-18	nf	nf	61	57

HT = high temperature; LT = low temperature; LD - long day; AT = ambient temperature; NL = natural light; nf » no flowering up to 20 June 1980; A = ambient temperature and daylength.
a. Scanty flowering.

Plant Height

Table 10 shows the genotypic treatment and G x T interaction plant height means, all of which were significant at the 1 % level of probability. The significant differences between treatment means suggest that the temperature and daylength levels generated by solar radiation and supplemental light under clear plastic are large enough to expose the inherent potential for vegetative growth and therefore serve as

Table 10. Mean plant height of seven pigeonpea genotypes In four daylength/temperature environments.

Treatment	Genotype							Treatment mean
	UW-17	IC-28	E-49	T3-42	34T-1	Code 1	E-18	
HT+ 14h L	209.8	210.5	192.8	200.3	206.3	203.3	191.8	202.1
LT+14h L	121.3	136.3	146.0	99.0	81.3	114.3	129.0	118.1
AT+14h L	97.5	102.0	89.3	94.5	98.3	115.5	53.8	93.0
AT + NL	48.0	53.3	38.8	30.0	44.8	63.0	38.5	45.2
Genotype mean	119.1	125.5	116.7	105.9	107.6	124.0	103.3	

SE of difference - Treatment 3.06
SE of difference- Genotypes 4.05
SE of difference -G x T 8.09
Error DF 84
Error S^2 130.8
HT = high temperature; LT = low temperature; AT = ambient temperature; NL = natural light.

a practical means of screening for plant height.

The genotype x treatment interaction in all but two instances was significant, indicating that no genotype in this experiment was completely insensitive to the two factors combined.

The method, however, could be employed to screen large populations. For such screening the ambient conditions and one other daylength/temperature environment might be sufficient. The latter may conveniently be generated in polyethylene-covered shelters provided with supplemental light. The temperature in the shelter could be maintained at about 5°C above the ambient temperature either by using an appropriate polyethylene material or by regulating the area covered by the polyethylene.

Summary

For the purpose of pigeonpea improvement, the Caribbean region may be considered as including not only the Caribbean islands, but also those countries of Central and South America where pigeonpea is of commercial importance. In this region the tall, indeterminate, and sensitive genotypes are required by small farmers; early-maturing grain types by small and large farmers, and daylength/temperature-insensitive types by both groups of farmers. The breeding program at the University of the West Indies is working towards satisfying these needs.

Segregating populations obtained from ICRISAT are being screened with the aim of filling the first two needs of the region. Breeding for daylength/temperature insensitivity is receiving major attention.

Research in the past4 years has indicated that not only daylength but also temperature and possibly factors such as soil moisture, fertility, etc., influence induction of flowers and preflowering vegetative growth. The latter is the major hurdle at the present time in popularizing year-round pigeonpea cultivation. In order to overcome this problem, dwarfing genes, wide crosses, and screening among pigeonpea germplasm for daylength/temperature influences are being investigated.

A proposal for using solar heat and extended light period as a means of screening for insensitivity is discussed.

References

ALI, C, and ARIYANAYAGAM, R. P. 1979. Floral induction and yield of dry matter in pigeonpea (*Cajanus cajan* [L.] Millsp.) under different daylength/temperature environments. Presented at the Regional Grain Legume Seminar, University of the West Indies, St. Augustine, Trinidad.

ARIYANAYAGAM, R. P. 1975. Status of research on pigeonpeas in Trinidad. Pages 131-139 *in* Proceedings, International Workshop on Grain Legumes. ICRISAT, 13-16 Jan 1975, Hyderabad, India.

ARIYANAYAGAM, R. P., and SPENCE, J. A. 1978. A possible gene source for early day length neutral pigeonpeas, *Cajanus cajan* [L] Millsp. Euphytica 27: 505-509.

JOSHI, S.N. 1973. Variability and correlation studies in Pigeonpea (*Cajanus cajan* [L.J). Madras Agriculture Journal 60 (6): 412-414.

KEATINGE, J. D. H. 1980. ODA/UWI Research Scheme R. 3245 final report. Faculty of Agriculture, University of the West Indies, St. Augustine, Trinidad.

MUNOZ, A. M., and ABRAMS, R. 1971. Inheritance of some quantitative characters in pigeonpea (*Cajanus cajan* [L] Millsp.). Journal of Agriculture, University of Puerto Rico 55(1): 23-43.

SINHA, S. K. 1977. Food legumes: distribution, adaptability and biology of yield. FAO Plant Production and Protection paper 3, FAO, Rome, Italy.

SPENCE, J. A., and WILLIAMS, S. J. A. 1972. Use of photoperiod response to change plant design. Crop Science 12: 121-122.

SUMMERFIELD, R. J. 1975. Some effects of air temperature on vegetative growth, flowering and seed yield of cowpea. Pages 130-134 *in* Proceedings, IITA Collaborators Meeting on Grain Legume Improvement. IITA Ibadan, Nigeria.

SUMMERFIELD, R. J. 1976. Use of glass houses as an adjunct to field research on soybeans. Pages 358-370 *in* Proceedings, World Soybean Research Conference (ed. L. 0. Hill).

Pigeonpea Improvement Research in Kenya

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Abstract

Studies on the degree of outcrossing in pigeonpea showed that outcrossing varies between 25.2 and 94.5%. Since cross-pollen produced 22% more hybrid seeds per pod than self-poll en, pigeonpea seems to prefer cross-pollination to self-pollination. Availability and activity of insect pollinators were the most important factors contributing to outcrossing. Seven genera comprising 24 species of pigeonpea pollinators are reported in Kenya. Two population improvement methods, namely, stratified mass selection (SMS) and mass selection with progeny testing (MSPT) were tested. Progress per cycle of selection of 2.3 and 4.3% under SMS and MSPT were realized in marginal rainfall areas. Mean grain yield of improved cultivars on farmers' fields was 2637 as compared with 1361 kg/ha of farmers' varieties. National surveys on farmers' fields showed that mean pigeonpea grain yields were 1492 and 1162 kglha in 1979 and 1980.

Pigeonpea (*Cajanus cajan* [L] Millsp.) is the most important grain legume in marginal rainfall areas of Kenya where it is grown to an area of approximately 100 000 ha annually; however, it ranks as the second most important pulse crop in Kenya after field beans *(Phaseolus vulgaris* L). Because of its importance in Kenya, a pigeonpea improvement project was initiated at the Department of Crop Science at the University of Nairobi in 1975to improve pigeonpea grain yields in marginal rainfall areas of Kenya.

A number of problems had to be solved before effective improvement of this crop by breeding could be realized. Pigeonpea is essentially a self-pollinated crop but it can outcross to varying degrees under Kenyan conditions. It was therefore necessary to study the extent of its outcrossing and the factors that influence outcrossing in this crop before suitable breeding methods and maintenance of genetic purity could be decided upon. Because studies indicated that this crop can outcross to a large extent under Kenyan conditions, it was decided that population improvement methods should be considered for pigeonpea improvement. Population improvement methods that were tested were: stratified mass selection (SMS), mass selection with progeny testing (MSPT), and S_1 testing. The last method was coupled with testing and comparing high-yielding selected cultivars with farmers' own varieties in the farmers' fields.

Finally, there is a general lack of information on status of pigeonpea yield levels and losses due to pests and diseases in the farmers' fields. Two national surveys have been conducted to furnish information on these and other agronomic factors. This paper reports findings on some aspects of these studies and surveys.

Studies on Degree of Outcrossing in Pigeonpea

According to reports from various parts of the world, pigeonpea outcrosses to varying degrees. Reports from India show that outcrossing in this crop varies between 0.1 and 48.0% (Howard et al. 1919; Mehta and Dave 1931; Shaw 1932; Kadam et al. 1945; Deshmukh and Rekhi 1962). Pigeonpea was reported to outcross between 14.0 and 15.9% in Hawaii (Wilsie and Takahashi 1934) and between 5.5 and 6.3% in Puerto Rico (Abrams 1967). Ariyanayagam (1976) reported outcrossing in pigeonpea to be 26.4% in Trinidad. The reported wide range of outcrossing indicates that although no self-

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incompatibility has been reported in pigeonpea, the crop has a pollination system that allows both self- and cross-pollination to take place readily. This makes maintenance of genetic purity of pigeonpea cultures costly. A number of experiments have been conducted to furnish information on the extent of outcrossing in pigeonpea in Kenya and the factors that influence it. These experiments are briefly described in this paper.

Estimating Insect Pollinator Activity

Inbred lines NPP-205/6 with purple stems and NPP-199/10 with green stems were used in these experiments. Three hundred seeds of each type were mechanically mixed before randomly planting one seed per hill at a spacing of 80 cm x 30 cm in a plot measuring 12 m x 12 m. The experiment was planted in 1976 at six sites in Kenya, including the following agricultural research stations: Katumani, Makueni, Kibos, and Mtwapa, as well as at two sites at the University Field Station at Kabete. At Kabete, one site had normal insect pollinator population while the other had a high insect pollinator population. The site under a high pollinator population was situated near an apiary with 30 beehives, attheedgeof aforestwell inhabitated by a wide range of other insect pollinators.

Activity of insect pollinators at each site was determined during anthesis. An area measuring 2 m x 2 m was marked at the middle of each plot, and all insect pollinators visiting flowers in that area within a period of 5 minutes were carefully counted between 0800 and 0900 hrs. Three such counts were taken at two-day intervals for each site.

The estimates of percent purple-stemmed progeny from green-stemmed parents are presented in Table 1. These results showed that percent purple progeny varied from 12.60 at Kibos to 45.91 at Kabete under high insect pollinator population. However, the experimental model used in this study only measures outcrossing between purple- and green-stemmed plants as indicated in the following equation:

Table 1. Estimates of percent purple progeny from six sites in Kenya from equal numbers of purple- and green-stemmed parents.

		No. of seedlings				Site mean
Site	Replicate	Total	(g)	(P)	Replicate	% (p) ± SD
Katumani	1	394	309	85	21.57	
	2	376	316	60	15.96	
	3	347	291	56	16.14	
	4	395	327	68	17.22	17.72 ± 2.62
Kibos	1	441	387	54	12.24	
	2	342	293	49	14.33	
	3	334	298	36	10.78	
	4	391	340	51	13.04	12.60 ± 1.47
Makueni	1	405	320	85	20.99	
	2	269	220	49	18.22	
	3	400	322	78	19.50	
	4	377	282	95	25.20	20.98 ± 3.03
Mtwapa	1	414	320	94	22.71	
	2	391	308	83	21.23	21.97 ± 1.05
Kabete (Low pollinator population)	1	142	122	20	14.08	
	2	89	60	29	32.58	23.33 ± 13.08
Kabete (High pollinator population)	1	258	143	115	44.57	
	2	218	115	103	47.25	45.91 ± 1.90

g = Green-stemmed seedlings; p = Purple-ttemmedseedlings; %(p) = Percent of seedlings with purple stems.

$$300 \text{ purple-stemmed plants} \underset{v}{\overset{u}{\rightleftharpoons}} 300 \text{ green-stemmed plants} \quad (1)$$

This equation is assuming that u = v, hence no selective foraging by insect pollinators. Since outcrossing was only measured in green-stemmed plants, it means that only u was determined, which is equivalent to half of the total degree of outcrossing. Moreover equation (1) does not take into account outcrossing among purple-stemmed plants nor green-stemmed ones, which in each case constitute one-fourth of the total degree of outcrossing:

$$150 \text{ purple-stemmed} \underset{v_1}{\overset{u_1}{\rightleftharpoons}} 150 \text{ purple-stemmed plants} \quad (2)$$

$$150 \text{ green-stemmed} \underset{V2}{\overset{U2}{\rightleftharpoons}} 150 \text{ green-stemmed plants} \quad (3)$$

Percent purple-stemmed progeny in Table 1 estimate only one-half of the total degree of outcrossing. Therefore, the mean percent purple-stemmed progeny for each site should be multiplied by a factor of 2 to givethe degree of outcrossing for that site. These estimates are presented in Table 2.

The estimated values for outcrossing in pigeonpea in Table 2 range from 25.2% at Kibos to 94.5% at Kabete under high insect pollinator population. These high values of outcrossing in pigeonpea point to the possibility that this crop may be improved by population improvement methods like other open-pollinated crops, as was proposed bv Khan (1973).

Table 2. Estimated degree of outcrossing in pigeonpea at six sites in Kenya.

Site	Site mean %(p)	Estimated degree of outcrossing (% [p] x 2) %
Katumani	17.72	35.44
Kibos	12.60	25.20
Makueni	20.98	41.96
Mtwapa	21.97	43.94
Kabete (Low pollinator pop.)	23.33	46.66
Kabete (High pollinator pop.)	47.25	94.50

p = Purple-stemmed; %lp) - Percent of seedling with purple stems.

Table 3. Relationship between insect pollinator activity and degree of outcrossing at six sites in Kenya.

Site	No. of pollinators/ 4 m^2 in 5 min (Mean ± SD)	Estimated degree of outcrossing (%)
Katumani	4.00 ± 2.00	35.44
Kibos	3.00 ± 1.00	25.20
Makueni	7.33 ± 2.08	41.96
Mtwapa	8.67 ± 3.79	43.94
Kabete (Low pollinator pop.)	9.00 ± 1.00	46.66
Kabete (High pollinator pop.)	22.00 ± 3.61	94.50

r= 0.994; p < 0.001

Table 3 presents insect pollinator activity at the various sites. There was a close positive relationship between insect pollinator activity and the degree of outcrossing at each site (r = 0.994; P<0.001).

Increasing Quantity of Pollen Grains

The aim of this experiment was to increase the quantity of pollen grains of purple-stemmed plants many times above those of green-stemmed plants per plot, without altering the insect pollinator population at each site. Since pollen grain yields per plant of the inbred lines, NPP-205/6 and NPP-199/10 were about the same, it was decided that a ratio of one green-stemmed plant to 50 purple-stemmed plants be used. In this experiment, a plot layout in which each green-stemmed plant was surrounded by three rows of purple-stemmed plants was used. The spacing was 80 cm x 40 cm and plots were 15 mx 15 m. The experiment was planted at three sites in Kenya, at Kabete under high insect pollinator population, Katumani, and Kibos.

The data on percent purple-stemmed progeny are presented in Table 4; although these are limited, these site means percent purple-stemmed progeny are very similar to those presented in Table 3 for Katumani and Kibos. However, since pollen of the purple-stemmed plants was 50 times more abundant in experiment II as compared with experiment I, much higher percentages of purple-stemmed proge-

Table 4. Estimates of percent purple seedlings when the number of purple-stemmed parents Is 50 times in excess of green-stemmed parents.

Site	Replicate	No. of seedlings Total	(g)	(P)	Replicate %(P)	Site mean %(p)±SD
Katumani	1	410	343	67	16.34	
	2	364	300	64	17.58	16.96 ± 0.88
Kibos	1	402	343	59	14.68	
	2	379	328	51	13.46	14.07 ± 0.86
Kabete (High pollinator population)[a]						

a. No seed was harvested because of very severe pest damage.

nies were expected. It was, however, concluded that the number and activity of insect pollinators was the major factor determining the degree of outcrossing in pigeonpea.

Factors Encouraging Outcrossing in Pigeonpea

Although pigeonpea outcrosses to a large extent, factors that encourage outcrossing in this crop have not been well understood. Onim et al. (1978) have reported a number of factors that influence outcrossing in this crop. Although pigeonpea sheds pollen while the flower is still in bud, the pollen grains did not start germinating on the stigmas until flowers started to wither 24 to 28 hours after anthers dehisced. This gives foreign pollen a good opportunity to be introduced onto the stigma by insect pollinators before pollen germination starts.

Level of pollen fertility varies among many entries in the Nairobi University pigeonpea germplasm bank, and a wide range from 100% pollen fertility to 100% genetic male sterility exists. Frequency of hybrids in pod-progenies under natural outcrossing showed that number of hybrid seedlings was 22% higher, which indicates that foreign pollen, irrespective of its quantity on the stigmas, had a 22% faster germination and pollen tube growth than self pollen. This phenomenon has been observed in an in vitro study in broad bean (*Vicia faba* L.) (Rowlands 1958) and in vivo in cowpea (*Vigna unguiculata* [L] Walp.) in Surinam (van Marrewijk, personal communication).

Availability and activity of insect pollinators was the major factor in the degree of outcrossing. The genera and species of some insect pollinators of pigeonpea in Kenya are presented in Table 5. These comprised seven genera, of which ten *Chalicodoma,* five *Megachile,* and five *Xylocopa* species were the major ones. Regarding their activity, *Chalicodoma* and *Megachile* species were extremely fast. Each flower visit lasted between 15 and 30 seconds, and members of these genera visited plants far apart, often many rows away, from flower to flower. *Xylocopa* species were, on the contrary, very slow. Each visit varied between 20 and 55 seconds. They visited several flowers on the same plant often following the same row. The African honeybee {*Apis mellifica adansoni* Ltr) was the most abundant at all locations. Because members of this species are smaller than *Chalicodoma, Megachile,* and *Xylocopa* species, they only manage to trip pigeonpea flowers with a lot of difficulty. However, their large numbers in a flowering pigeonpea crop definitely compensate for their inefficiency.

Foraging habits of the various pigeonpea pollinator species would influence the extent of outcrossing. All insect pollinators visiting pigeonpea flowers seemed not to visit flowers of other plant species during the same foraging trip. The ventral sides of their abdomens and pollen baskets were often full of pigeonpea pollen. Williams (1977) counted between 5500 and 107 333 pollen grains on single *Xylocopa* and *Megachile* pollinators in India, of which pigeonpea pollen was generally 98 to 100%.

Insect pollinators tripped almost all newly opened pigeonpea flowers by the end of the day, thereby helping to shake up self-pollen onto the stigma, but, more significantly, introducing genetically different pollen from other pigeonpea genotypes. The contribution of in-

Table 8. Important insect pollinators of pigeonpea in Kenya.

Pollinator	Katumani	Makueni	Kibos	Kabete
Chalicodoma rufiventris Guerin	X	X	X	X
C. congruens natalensis Friese	X	X		
C. bombiformis Gerstaecker	X	X	X	X
C. torrida torrida Smith			X	
C. neavei Vachal	X	X		
C. cincta combusts Smith	X	X	X	X
C. cincta nigrocincta Ritsema	X	X	X	X
C. bombiformis bombiformis Gertaecker	X	X	X	X
C. felina feline Gerstaecker	X	X	X	X
C. torrida pachingeri Friese	X		X	
Megachile wahlbergi Friese	X	X	X	X
M. nasalis Smith			X	
M. fulvitarsis Friese				X
M. apiformis Smith	X			
M. bituberculata Ritsema	X		X	X
Xylocopa flavorufa DeGeer	X	X	X	X
X. *inconstens* Smith	X	X	X	X
X. spec. *aff. calens* Lepeletier	X		X	
X. *spec. aff. enderlein* Schulz	X		X	
X. *aff. caffra* L.	X	X		X
Amegilla plumipes Fabricius			X	
Apis mellrfica adansoni Ltr.	X	X	X	X
Crocisa sp.		X	X	
Lampides boeticus L.	X	X	X	X

x indicates the site where the pollinator was found.

sect pollinators is no doubt the most important factor in pigeonpea outcrossing.

Population Improvement Methods in Pigeonpea in Marginal Rainfall Areas of Kenya

Because of the wide range of outcrossing in pigeonpea, Khan (1973) proposed that pigeonpea composites should respond to selection by population improvement methods. To test this, two population improvement methods, namely stratified mass selection (SMS) (Gardner 1961) and mass selection with progeny testing (MSPT) were tested on an early-maturing pigeonpea composite population. Effects of these selection methods on grain yield and other morphological characters are reported here.

Stratified Mass Selection

In the first rainy season of 1975, 14 composites and 60 lines of early-maturing pigeonpea cultivars were planted at a spacing of 80 cm x 30 cm. Because of a severe drought, only 671 plants developed to maturity, of which 199 (30%) were selected on the basis of their apparent pod yields. At harvesting, four pods were harvested from each of the 671 plants and bulked to constitute the original population (Co). On the basis of grain yields, 67 plants (10%) were finally selected. Seed of theselected plants was divided into three equal portions, of which one was kept in cold storage as remnant seed for MSPT, one was used in progeny testing for MSPT, and in the last one, equal numbers of seeds per plant were mixed to form $SMSC_1$ population.

SMSCi composite was planted at the National Dryland Farming Research Station, Katumani, in a block measuring 15 m x 16 m in October 1975. At mid-pod-filling, the plot was divided into 18 cells by means of a string grid. Based on apparent pod yield, eight plants were initially selected per cell, of which only two were finally selected (10%). This procedure was repeated until four SMS selection cycles were completed, finally resulting in the formation of $SMSC_4$ population.

Mass Selection with Progeny Testing

In October 1975, part of the seed from 67 selected plants was planted at Katumani in 2-m single-row plots in two replicates. After harvesting and weighing grain yields, means of progeny lines were ranked and only 35 (5%) of the original population were finally selected. Remnant seed of the selected "lines" was retrieved from cold storage and equal numbers of seeds were mixed to form improved composite, $MSPTC_1$. This seed was mechanically mixed thoroughly before planting at Katumani in April 1976. At mid-pod-filling, 202 plants were selected from a population of 929 plants, based on the same criteria. Before harvesting, two pods were harvested from each plant and bulked to constitute the MSPTCi population. On the basis of grain yields, 93 plants (10%) were selected, and their progeny tested, after which 5% of the previous population was finally selected. This process was repeated when forming the MSPTCi population.

Replicated Yield Trials of SMS and MSPT Improved Populations

Four improved SMS populations, two MSPT *populations, and the unimproved population* were planted in replicated trials at three locations in October 1977. The locations — Katumani, Thika and Makueni — are all in marginal rainfall areas. The experiment was planted in a randomized block design with five replicates at each location. Each population was planted in a plot measuring 4 m x 2.4 m, and each had four rows of plants, of which only the two inner rows were used for various measurements. Grain yield per plant was determined after it was dried at 40°C for 24 hours. Two plants per plot were sampled at mid-pod-filling and dried at 100°C for 24 hours before weighing.

The trial was repeated in October 1978 at the same locations.

Dry matter of shoot and grain yields of the populations in 1977 are presented in Figure 1. Grainyields of the populations in both 1977 and 1978 and the means of the two growing seasons are presented in Table 6.

The mean grain yield in SMS populations indicated a progress per cycle of selection of 2.3% after four cycles of selection. Selection under MSPT, however, indicated a progress per cycle of selection of 1.9% over two selection cycles. However, in the first cycle, the progress was 8.2%. By regression, the approximate progress per cycle was therefore 4.3%.

Table 6. Grain yiald/plant (g) at three locations ovet two growing seasons.

	Location						Population mean		
	Katumani		Thika		Makueni				
Population	1977	1978	1977	1978	1977	1978	1977	1978	of two seasons
Original (Co)	21.5	8.9	34.7	23.2	40.2	18.0	32.1	16.7	24.4
$SMSC_1$	20.4	7.6	35.2	27.6	38.4	24.0	31.3	19.7	25.5
$SMSC_2$	21.4	10.9	34.4	24.8	35.4	14.1	30.4	16.6	23.5
$SMSC_3$	18.1	11.2	31.8	30.1	40.5	25.0	30.1	22.1	26.1
$SMSC_4$	22.4	12.5	35.6	32.9	38.2	18.1	32.1	21.2	26.6
$MSPTC_1$	21.0	8.8	36.7	31.6	41.1	19.4	32.9	19.9	26.4
$MSPTC_2$	20.7	7.6	35.6	29.5	39.6	19.0	32.0	18.7	25.3
LSD (5%)	5.7	5.5	8.7	11.1	8.7	8.6	2.8	5.2	2.9
CV(%)	21.0	43.9	19.1	29.8	17.0	33.5	4.9	15.1	9.7

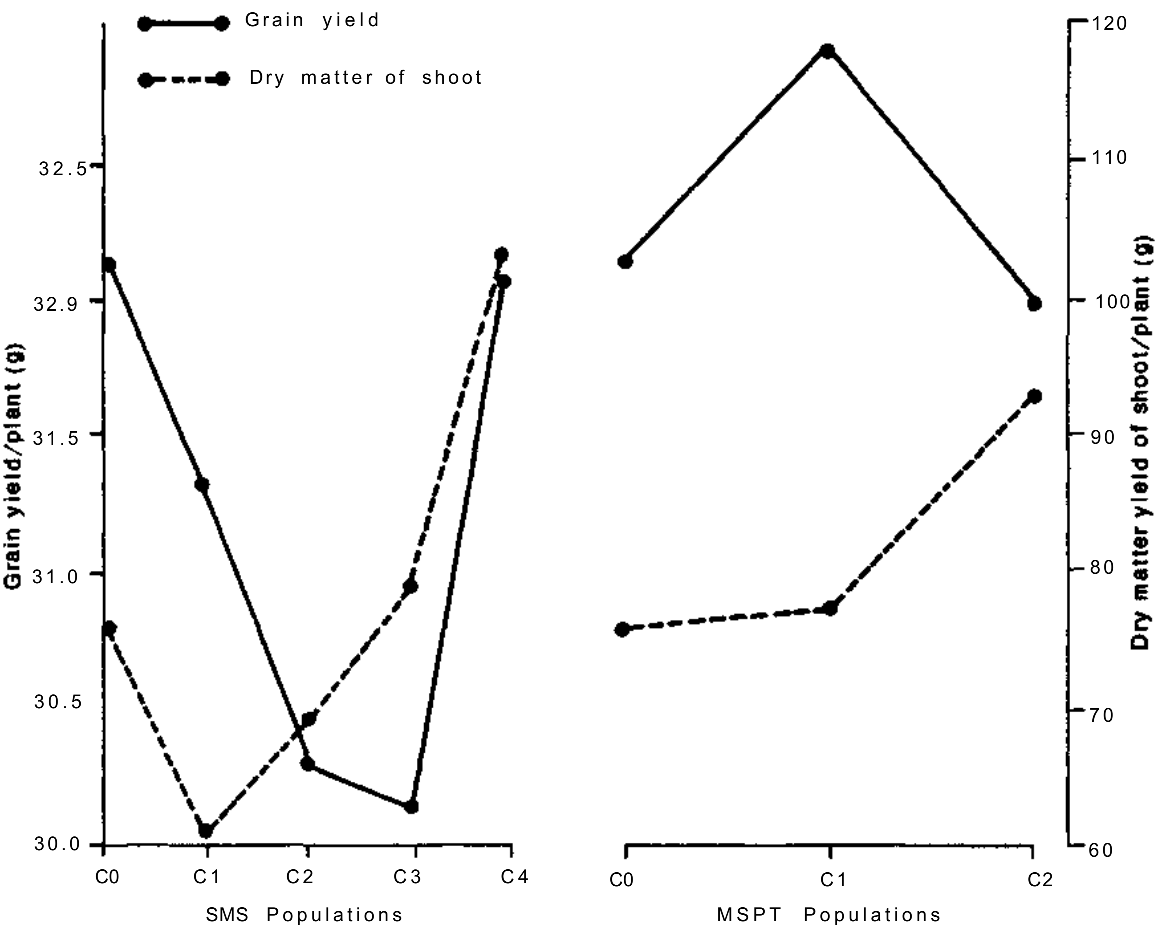

Figure 1. Mean grain and dry-matter yields of shoot of Co, SMS, and MSPT populations in 1977.

S_1 Testing of Local Pigeonpea Cultivars

In 1976, a major germplasm collection of local pigeonpea cultivars in Kenya was jointly done by the pigeonpea project at the University of Nairobi and ICRISAT. Further smaller germplasm collections have been made every year since then.

In 1976, about 400 germplasm entries were screened at Katumani, and several single plants were selected and selfed. In 1977, 11 best yielding selfed plants were tested in replicated yield trials at three research stations at Thika, Makueni, and Kibos. From the 11 tested cultivars, six high-yielding ones were selected for further testing on farmers'fields. In 1979, the six high-yielding cultivars were given to 12 farmers (two farmers per cultivar) in Makueni Division of Machakos District. Each farmer was given 3 kg seed and told to plant half of the field with the improved cultivar and the other half with their own varieties. The farmers were further instructed to use traditional husbandry methods of their own choice. Two of the improved cultivars (Table 7), numbers 9 and 10, were also planted at Makueni Research Station at a higher plant density than in most farmers' fields.

At maturity, a quadrat measuring 3 m x 3 m was placed at representative parts of the field in both farmers' varieties and improved cultivars. Plant densities, plant height, and number of primary branches were determined within the quadrat before the enclosed plants were harvested. A number of parameters of the two cultivars in each field were later measured. These included number of pods and grain yield per quadrat, mean number of seeds per pod,

Table 7. Plant densltles and eomparison of grain yieids, 100 seed weight, and paat damage between farmers' varieties and improvad pigeonpea cultivars in farmer's fields In Kenya.

Field No.	Plant population/ha	Grain yield (kg/ha)		100-seed wt (9)		Pest damage (%)			
						Pods		Seeds	
		Farmers'	Improved	Farmers'	Improved	Farmers'	Improved	Farmers'	Improved
1	11 100	1014	1551	22.64	20.47	10.6	5.6	3.0	1.2
2	21 100	2093	2197	24.66	19.87	15.5	6.7	3.1	2.0
3	34 400	1251	2567	22.16	25.06	7.8	9.8	3.2	3.2
4	14400	731	4262*	21.25	17.32	9.0	9.0	3.0	3.0
5	32 200	2150	2476*	21.72	22.84	3.6	9.5	1.0	2.4
6	23 300	1763	4602*	22.88	24.08	12.3	4.2	3.5	1.5
7	22 200	804	1418	25.57	22.42	13.3	10.0	3.0	3.9
8	22 200	1081	2019	24.34	21.42	8.3	10.9	2.7	3.1
9	35 600				20.60		22.2		6.9
10	37 800				23.60		18.9		3.6
Mean	25430	1361	2637	23.15	21.77	10.1	10.7	2.8	3.1

* Cuitivars selected for further prerelease testing.

100-seed weight, and extent of pest damage on pods and seeds. Yields were expressed in kilograms per hectare in each case.

Results in Table 7 show that differences between the farmers' varieties and improved cultivars were very small in all characteristics, except grain yields. The mean yield in farmers' varieties was 1361 kg/ha as compared with 2637 kg/ha in improved cultivars. The improved cultivars therefore outyielded the farmers' varieties by 93.8%. Considering not only grain yields but also other agronomic characters, three cultivars Nos. 4,5,6 in Table 7) have been selected to undergo further testing before one or all of them are released as new varieties. Seeds of the two highest yielding cultivars, numbers 4 and 6, have been distributed to 300 farmers in Makueni Division for 1980 planting.

Two of the improved cultivars — numbers 2 and 8 — showed very high susceptibility to *Fusarium* wilt. Pest damage was on the average lower than had been anticipated. However, pest damage seemed to be more severe under research station conditions than farmers' growing conditions, as shown in Table 7 for cultivars 9 and 10. The reasons for this are not clear, but it may be that under research station conditions the crop was isolated and therefore became a focal point for pest attack. In the farmers' conditions, however, several fields were grown adjacent to one another and the pest load may have been diffused over a much larger crop area. This observation needs further studies.

National Surveys on Pigeonpea Yield and Disease and Pest Damage in Farmers' Fields

Two national surveys on pigeonpea grain yields and on diseases and extent of pest damage were conducted, one in 1979 and the other in 1980. Pigeonpea fields approximately 20 km apart along major and medium-sized roads in Machakos and Kitui Districts were surveyed. In each case, a quadrat measuring 3 m x 3 m was placed in a representative part of the field, then plant density in the quadrat, plant height, and number of primary branches were determined on five randomly chosen plants. All plants in the quadrat were then harvested and grain yields later measured. Diseases in the field were recorded and the extent of damage caused by them estimated. In wetyears, a leafspot disease caused by the fungus *Mycovellosiella cajani* (Henn) Rangel ex Trotter (Syn: *Cercospora cajani* Henn. = *Vellosiella cajani* Rangel) causes severe defoliation and consequently grain yield losses of up to 85% (Onim 1980). However, in normal years, *Fusarium* wilt is the major disease, affecting approximately 5% of plants in the field. However, higher estimates of up to 60% have been observed. Sterility mosaic disease has been sporadic. In 1980, jassids were widespread. However, pest damage on both pods and seeds, caused mainly by *Heliothis* and *Melanogromyza,* was moderate. Results of these surveys are presented in Table 8.

Conclusions

The degree of outcrossing reported in this paper (up to 94.5%) is quite high when compared with most of the values reported in the available literature. The main reason for these differences may lie in the methods used by various people for estimating outcrossing on this crop. Similarly, the evidence reported in this paper that cross-pollen gave rise to 22% more hybrids in pod progeny under conditions of natural pollination seems to indicate that this crop has a pollination mechanism that prefers cross-pollination to self-pollination. In view of these observations, breeding methods of pigeonpea should be reconsidered so that population improvement methods are also included. The model for open-pollinated crops is maize *(Zea mays* L) whose selfing and crossing are easy. However, selfing and artificial crossing in pigeonpea are costly considerations. We in Kenya have therefore attempted to test population improvement methods in pigeonpea on composite populations, thus bypassing these difficulties.

The progress per cycle of selection realized under SMS and MSPT of 2.3% and 4.3% supports the high degree of outcrossing observed in pigeonpea under Kenyan conditions. Gard-

Table 8. Plant densities, height, number of primary branches, grain yields, and past damage of pigeon pea on farmers' fields in Kenya.

Field No.	Population/ha		Plant height (cm)		No. of primary branches		Grain yield (kg/ha)		Pest-damaged pods (%)
	1979	1980	1979	1980	1979	1980	1979	1980	1980
1	23 300	11 100	347.4	289.0	25.6	17.8	1028	1014	10.6
2	12 200	21 100	305.06	284.6	27.0	19.6	1186	2093	15.5
3	43 300	34 400	345.2	259.2	22.6	19.2	1242	1251	7.8
4	18 900	14 400	274.8	306.0	19.4	28.0	1450	731	9.0
5	17 780	32 200	333.8	252.2	22.8	19.2	1903	2150	3.6
6	11 100	23 300	339.4	239.0	26.0	24.6	1532	1763	12.3
7	21 000	22 200	288.2	217.2	19.4	12.2	1600	804	13.3
8	12 200	22 200	259.6	293.4	19.2	21.4	1431	1081	8.3
9	10 000	35 600	263.2	289.0	21.2	23.8	1191	606	22.2
10	11 100	37 800	264.8	271.8	19.4	14.2	2493	1012	18.9
11	10 000	41 100	272.2	284.0	23.8	15.2	1229	1553	5.4
12	21 100	17 800	368.0	213.0	28.0	12.8	2136	691	25.4
13	25 600	33 300	331.0	199.6	26.6	11.6	980	699	14.5
14	24 400	17 800	345.6	253.8	26.2	18.8	1019	862	17.0
15	15 600	14 400	343.0	243.6	26.4	18.0	1368	729	12.0
16	28 900	64 400	291.6	245.2	24.4	14.2	938	516	15.7
17	18 900	10 000	325.4	274.4	25.0	18.4	1449	1286	19.5
18	13300	25600	334.2	289.0	30.4	17.2	1866	1186	14.4
19	12 200	20 000	336.6	301.2	25.6	19.2	1153	2018	13.4
20	31 100	18 900	351.2	321.6	27.0	18.6	2202	1192	7.3
21	22 200		357.8		26.4		1931		
Mean	19 251	25 900	318.0	266.4	24.4	18.2	1492	1162	13.6

ner (1961) reported progress of 3.9% when he used SMS to improve grain yields in maize. These findings show that pigeonpea composites can be improved by population improvement methods so that rather than minimize outcrossing, insect pollinators should be used to create genetic variability on which selection can be based. However, partitioning of dry matter between grain and vegetative parts should be investigated if maximum use of this approach is to be realized. Testing on the farmers' land is a new approach that will narrow the gap between researchers' and farmers' yield figures when new varieties are released. This approach should be encouraged.

National surveys have indicated that pigeonpea yields on the farmers' fields in Kenya are quite high. In Uganda, Dunbar (1969) reported pigeonpea yields in the farmers' fields to be 168 kg/ha. However, the methods used in arriving at some of these statistics can be very misleading. These yield levels at the farmers' fields have given breeders in Kenya a bench mark from which breeding for yield should start.

Finally, yield losses due to diseases and pests on the farmers' fields should be quantified as these surveys attempted to do. Thereafter, priorities on control of such diseases and pests can be set more appropriately.

Acknowledgment

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References

ABRAMS, R. 1967. Studies on natural cross pollination in pigeonpea *(Cajanus cajan).* Journal of the Agricultural University of Puerto Rico 57(1): 1-3.

ARIYANAYAGAM, R. P. 1976. Outcrossing and isolation in pigeonpea. Tropical Grain Legume Bulletin 5: 236-240.

DESHMUKH, N. T., and REKHI, S. S. 1962. Study of natural crossing in pigeonpea (*Cajanus cajan* [L] Millsp.). Proceedings, Bihar Academy of Agricultural Sciences 8-9: 135-139.

DUNBAR, A. R. 1969. Pages *68-70 in* the annual crops of Uganda. EastAfrican Literature Bureau, Kampala, Uganda.

GARDNER, C. O.1961. An evaluation of effects of mass selection and seed irradiation with thermal neutrons on yield of corn. Crop Science 1: 241-245.

HOWARD, A., HOWARD, G. L. C, and KHAN, A. R. 1919. Studies in the population of Indian crops. I. Memoirs, Department of Agriculture in India, Botanical Series 10: 195-200.

ICRISAT. 1974. Pigeonpea breeding. Pages 158-168 *in* ICRISAT annual report, 1974-75. India: ICRISAT, Patancheru, Andhra Pradesh 502 324.

KADAM, B. S., KULKARNI, R. M., and PATEL, S. M. 1945. Natural crossing in *Cajanus cajan* (L) Millsp. in the Bombay Deccan. Indian Journal of Genetics 5: 60-62.

KHAN,T.N. 1973. A new approach to the breeding of pigeonpea (*Cajanus cajan* [L] Millsp.): formation of composites. Euphytica 22(3): 373-377.

MEHTA,D. N., and DAVE, B. B. 1931. Studies in *Cajanus indicus.* Memoirs, Department of Agriculture in India, Botanical Series 19: 1-25.

ONIM, J.F. M. 1980. Foliar fungicides for the control of *Mycovellosiella cajani* causing the leafspot of pigeonpea. Indian Journal of Agricultural Sciences 50(8): 615-619.

ONIM, J.F. M.,EIJNATTEN,C. L.M. VAN,and PATHAK,R. S. 1978. Some factors which encourage outcrossing in pigeonpea. Pages 219-225 *in* Proceedings, Fourth International Symposium on Pollination. Maryland Agricultural Experiment Station special miscellaneous publication 1, Maryland, USA.

SHAW, F. J. F. 1932. The breeding of *Cicer* and *Cajanus.* Bulletin of the Imperial Bureau of Plant Genetics 7: 14-16.

WILLIAMS, I. H. 1977. Behaviour of insects foraging on pigeonpea *(Cajanus cajan* [L] Millsp.) in India. Tropical Agriculture 54(4): 355-363.

WILSIE, C. P., and TAKAHASHI, M. 1934. Natural crossing in pigeonpea. Journal of Agricultural Research 49(10): 923-925.

Methodology and Progress in the ICRISAT Pigeonpea Breeding Program

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Abstract

This paper is primarily concerned with investigations of breeding methods and progress in yield improvement of pigeonpea (Cajanus cajan *[L] Millsp.). Features of the species — including specificity of adaptation, photoperiod reaction, outcrossing, and multiplicity of cropping systems — that influence decisions in the breeding program are discussed. The efficacy of different breeding methods, pedigree selection, bulk hybrid advance by single pod descent and mass selection, population breeding, and heterosis breeding are presented. Pedigree selection has been useful in breeding for highly heritable traits such as sterility mosaic disease resistance, seed size, and seed number per pod. In view of the minimum efforts of selfing required and apparent ineffectiveness of pedigree selection for breeding for yield per se, bulk hybrid advance by single pod descent appears to be a better procedure for breeding high yielding lines. The potential of F_1 hybrids in increasing production of this crop is indicated. Influence of cropping systems on selection and progress in breeding for disease resistance are presented.*

The proposed pigeonpea (*Cajanus cajan* [L] Millsp.) breeding program at ICRISAT was reported by Sharma and Green (1975). Emphasis was on developing disease and insect resistance and increasing yield. This paper is concerned primarily with investigations of breeding methods and progress in yield improvement. An important consideration in our breeding objectives is the maintenance of variability in advanced material to permit final selection for local adaptation by national program breeders. However, in studying breeding methods, we derive advanced lines for evaluation, and also select for specific adaptation at each of our breeding centers. Features of the species that influence decisions in the breeding program are discussed first as background information.

* Pulse Improvement Program and Farming Systems Research Program, ICRIBAT.

Special Characteristics of Pigeonpea

Specificity of Adaptation

Early in the program we corroborated the conventional wisdom that cultivars of 160 to 180 days' maturity were best adapted to the Hyderabad area with an annual precipitation of 760 mm (Figure 1,1974). With a strong relationship between total dry-matter production and grain yield, early cultivars gave lowgrain yields during 1974, which was a near-normal rainfall year (897 mm). Late cultivars, on the other hand, produced adequate dry matter, but suffered from drought in the pod formation and filling period. Also, when the early crop flowered and set pods under rainy conditions, pod-borer damage was excessive. However, in the 1975 crop season (Figure 1,1975) the latest cultivars gave the highest yields because of the unusually heavy rainfall (1158 mm).

To breed for adaptation to the typical local

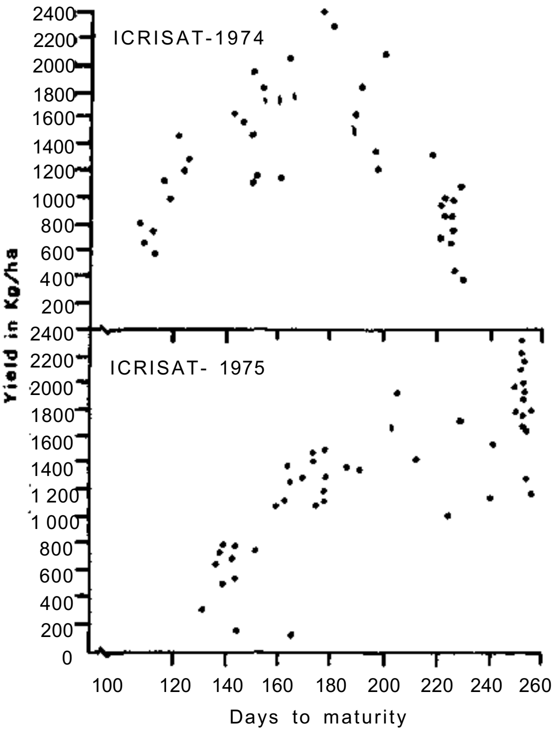

Figure 1. Yields of cultivars of different maturity tested at ICRISAT Center in 1974 (normal rainfall year) and 1975 (heavy rainfall year).

environments, wefound it essential to move the breeding work on early material to an area with a short monsoon (Hissar, 29°N latitude; 350 mm rainfall) and to move the late material to a north Indian location with adequate rainfall (Gwalior, 26°N latitude; 900 mm rainfall). Work on medium-maturity types is being continued at ICRISAT Center, Hyderabad (17°N latitude; 760 mm rainfall), which, in addition, serves as a nucleus of research activities at the subcenters.

Photoperiod Reaction

Pigeonpea is a quantitative short-day plant, with an apparent stricter daylength requirement in late than in early-maturing lines. From monthly plantings of several lines started in January 1974, we learned several things of importance to the breeding program: (1) Early and medium types (which mature in less than 160 days in July plantings) planted as late as January matured in 5 months or less. This permits the growing of two generations per year of this material at Hyderabad. (2) Late planting reduced plant size. Thus late planting permits the advancing of breeding material in bulk with limited competition. (3) In addition, reduced plant size in later plantings permitted the use of cages of reasonable size to exclude pollinating insects.

Only incidental to breeding, but of importance to production research, was the stimulation of investigation of dry-season planted pigeonpea as an alternative cropping system.

Outcrossing

Recent investigations indicate that the average 20% outcrossing assumed by Sharma and Green (1975) may be realistic for ICRISAT Center, but investigations are continuing. We hypothesized that delaying selection to advanced generations (and selecting for uniform progenies) would reduce the artificial selfing required to develop lines sufficiently homozygous to maintain their identity over years. As brought out in later sections, the outcrossing by insects can be beneficial in some breeding methods.

Multiplicity of Cropping Systems

Within a given maturity class pigeonpea plantings can vary from sole crops to widely spaced single rows in an intercrop, with a large number of variations between these two limits. This variation in cropping pattern is one of the special problems of pigeonpea breeding (Sharma and Green 1975). Much work remains to be done on adaptation to specific cropping patterns; relevant work at ICRISAT is summarized later in this paper.

Breeding Methods

Selection in the Germplasm

The large collection of germplasm at ICRISAT contains a tremendous amount of variability. Most of the landraces collected *are* highly heterogeneous, necessitating pedigree selection and selfing to produce pure lines carrying desirable characters such as disease resistance. To evaluate the possibility of selecting agronomically superior lines directly from the germplasm, individual plants were selected from visually rated good collections in the 1974 planting. These were planted in two-row plots with frequent checks. Of 339 planted, 32 medium-maturing and 27 late-maturing lines were selected for replicated tests.

The medium-maturity lines have been tested in both sole and intercropping for the past 4 years. After 2 years of testing, four of the selections were retained for further evaluation. Results of 4 years of testing show an average yield advantage for cv 185-9 in sole crop and for cv 2223-3 in intercrop (Table 1). ICP-1-6 has resistance to wilt and tolerance to sterility mosaic disease, with acceptable yield in intercrop. These results indicate that the germplasm is a worthwhile source for making selection.

Two years of testing of the late germplasm selections made at ICRISAT Center has failed to identify lines superior to the late check T-7. New late germplasm selections are being included in a new cycle of testing at Gwalior.

Hybridization and Selection

Choice of Parents

The importance of genetic diversity for improving yield potential per se has been emphasized by several authors and reviewed by Frey (1971). For our initial crosses, diverse parents were selected on the basis of differences in maturity, number of seeds per pod, and seed size, the latter two being highly heritable components of yield. Most of the cultivars adapted for dry-grain production in India had fewer seeds per pod and smaller seeds than the less common vegetable types from the tribal regions of central India and the Caribbean countries.

In our first season, 1973-74,107 crosses were made between two early grain types, T-21 and Pusa Ageti, and large-seeded medium and late vegetabletypes. Pedigree selection in segregating populations of these crosses was effective for maturity, seed size, and number of seeds per pod. However, it was apparent that handling of segregating populations from crosses of parents of widely different maturity was difficult at ICRISAT Center because of the difficulty of controlling pod borers on the early-maturity segregants, which flower and set pods under rainy conditions. At Hissar, where early lines are adapted, it is easier to utilize such crosses by simply discarding all late segregants. However, as improved lines have been developed, we have shifted to using an improved adapted cultivar as one parent and a derived line, of similar maturity with large seed size and more seeds per pod, as the other parent, to avoid the problems of handling very diverse maturity crosses.

To improve medium and late types, selection of parents was on the basis of yield potential, maturity, compensating yield components, and/or special traits such as high branch number or disease resistance.

Table 1. Comparative performance of four medium-maturity germplasm selections and three check cultivars in sole crop and in inter crop with maiza or sorghum at ICRISAT Center on Vertisol.

	Sole crop yield (kg/ha)					Intercrop yield (kg/ha)				
Cultivar	1977	1978	1979	1980	Mean	1977	1978	1979	1980	Mean
185-9	1702	1699	1582	1669	1663	915	850	1331	894	998
ICP-1-6	1496	1428	1768	1334	1507	1042	740	1300	885	992
2223-3	1510	1407	1848	1305	1518	1092	815	1610	993	1128
6962-6	1539	1525	1973	1285	1581	915	842	1620	927	1076
C-11[a]	1666		1661	1309	1545[b]	851		1489	926	1089*
BDN-1[a]	1822		1610	1301	1578[b]	574		1381	767	907*
ICP-1[a]	1503	1389	1660	1222	1444	858	756	1243	775	908
CV%	11.9	25.1	10.5			14.9	25	10.5		
LSD	285	NS	243	220		218	NS	243	220	

a. Check;
b. Mean of 3 years only.

Mating Systems

SINGLE CROSSES. For single crosses either the diallel or line x tester mating system was used. Diallel analyses have shown that the estimated general combining ability of the parents was highly correlated with the per se mean performance of the parents, but that array means provided a better estimate. In the light of this information most of the crosses for the practical breeding program are now being made in a line x tester scheme, using three or four well-adapted cultivars as testers. Using this method, the value of a new parent can be determined on the basis of its mean performance across testers. F_1s are planted in two or three row plots, flanked by the parents. F_1 performance is determined as a percentage of the tester parent.

TRIPLE CROSSES. Hartwig (1972), while emphasizing the importance of new germplasm in soybean breeding, suggested that one or more backcrosses to the adapted parent were useful in retaining the productivity and adaptation to the given environment. Crossing with an appropriate third parent in a triple cross is likely to produce a similar result. Thorne and Fehr (1970a, 1970b) and Frey (1972) observed that three-way crosses produced more lines superior for yield and protein than two-way crosses, when crosses were made using new germplasm. We have found that crossing a single cross of divergent parents to a well-adapted variety has provided excellent material for selection.

Selection Among Crosses

Green et al. (1979) summarized the work on the relationship between generations in pigeonpeas and concluded that the low-yielding crosses can be safely rejected on the basis of F_1 performance. However, they suggested that crosses that are high-yielding in the F_1 should be tested in the F_2 generation, since F2 performance is a better indicator of cross performance in succeeding generations. Sufficient seed supply in the F2 generation permits replicated multilocation tests for evaluating bulk populations for adaptation.

Observations on pigeonpea have shown that, due to local adaptation for maturity, hybrids between late and medium types tested in diverse environments show a very high genotype-environment interaction. At Hyderabad, a hybrid that is intermediate in maturity between the two parents may yield more than the adapted medium-duration parent, while at Gwaliorthe intermediate-maturity hybrid yields less than the adapted late parent. Therefore, the testing of F2 bulks for yield should be limited to crosses of adapted parents, and testing should be restricted to the region of adaptation.

ICRISAT has initiated muitilocation testing of F_5 bulk populations derived by single pod descent of medium and late maturity, in cooperation with the All India Coordinated Pulse Improvement Program. Busch et al. (1974) stated that "yield testing of carefully maintained bulks could be a very efficient method to select crosses." Thus, low-yielding populations can be eliminated, and resources can be concentrated on populations most likely to provide superior lines.

Pedigree Selection

Effectiveness of pedigree selection depends upon how truly the phenotype of the individual plant in a segregating generation reflects its genotype. Selection based on single-plant yield in early segregating generations has been highly ineffective in barley (Bell 1963), wheat (McGinnis and Shebeski 1968) and chickpea (Byth et al. 1980). Factors resulting in low heritability of yield in early generations include environmental variation, nonadditive gene effects in heterozygous plants, and high genotype-environment interaction. In pigeonpea we observed, in an F2 diallel test of 10 parents, that the variance of individual plant yield in some of the parents and the F2S was of a similar order (Table 2). At first, we questioned the genuineness of our crosses, the accuracy of our calculations, and the purity of the parents. However, Hamblin (1977) observed similar results in *Phaseolus* and concluded that "cross variance for characters which are markedly influenced in their relative expression by the environment (of which yield is the outstanding example) has little relevance as a criterion for deciding the relative worth of different crosses at crop densities." It can also be concluded that selection for yield would not be effective in populations where environmentally caused var-

Table 2. Means and variance of yield (g/plant) for some of the crosses and their parents in a 10 x 10 F_2 diallel study.

Cross	P_1		P_2		F_2	
	Mean	Variance	Mean	Variance	Mean	Variance
NP(WR)-15 x 102	40	344	65	1205	57	769
NP(WR)-15 x BDN-1	40	344	66	882	61	680
NP(WR)-15 x 1258	40	344	36	646	39	538
GW-3 x 1258	35	318	36	646	45	612
7086 x 102	22	166	65	1205	59	854
7086 x BDN-1	22	166	66	882	65	845
7086 x 1258	22	166	36	646	37	511
KWR-1 x 102	32	392	65	1205	52	975
KWR-1 x 1258	32	392	36	646	37	427
PS-66 x TTB-7	29	680	29	214	37	356
PS-66 x BDN-1	29	680	66	882	57	746
PS-66 x 1258	29	680	36	646	43	378
TTB-7 x 102	29	214	65	1205	57	942
TTB-7 x 1258	29	214	36	646	45	615
TTB-7 x 7977	29	214	30	393	26	202
102 x BDN-1	65	1205	66	882	58	665
102 x 1258	65	1205	36	646	66	975
102 x 7977	65	1205	30	393	55	799
BDN-1 x 1258	66	882	36	646	66	696
BDN-1 x 7977	66	882	30	393	63	690

iance is great. (Hamblin, 1977, concluded that *interpiant competition was the chief factor of* the environment responsible for the high variance of pure lines.) Interplant competition could be eliminated by wide plant spacing. The honeycomb method of Fasoulas (1973) was considered, but the extreme plant spacing required to eliminate competition in pigeonpea made the method appear impractical. Therefore, it was concluded that selection for yield must be based on progeny or family performance. For this purpose, Knott (1972), De Pauw and Shebeski (1973), and Sneep (1977) have suggested unreplicated progeny yield tests, with progeny performance measured as a percentage of the moving average of adjacent progenies or frequent check plots.

At ICRISAT, we adopted progeny testing in two-, three- and four-row plots, with every third, fourth, and sixth plots as check in F3, F4, and Fs-F7 generations, respectively. The overall results to date are not very encouraging, since advanced lines selected by this method, when tested in replicated yield trials at ICRISAT Center, Hyderabad, did not show *any* convincing improvement in yielding ability over the check cultivar. There are not many studies on the critical evaluation of the system in an applied breeding program. It may be necessary to evaluate further the effectiveness of the method, possibly on multilocation observations to avoid the unpredictable bias caused by the genotype-environment interaction over years.

Knott (1979) evaluated the effectiveness of selection based on F3 yield tests (YT) againstthe lines derived by single-seed descent (SSD) in wheat. He concluded that the SSD lines appeared to be as useful as the YT lines and a great deal less work was required in their production. However, Thakre and Qualset (1978) observed that selection of the best plants within the F3 family selected on the basis of yield, was a useful selection procedure.

In pigeonpea, pedigree selection has been an excellent procedure for selecting simply inherited characters, including resistance to some diseases, and highly heritable quantitative characters, including days to flowering, seeds per pod, seed size, and plant height. Considerable success has been achieved in selecting for these characters in our project on breeding for early types and vegetable types. The substantial yield advantage of newly developed early lines over standard checks is illustrated in Table 3.

HANDLING OF THREE-WAY CROSSES BY THE PEDIGREE METHOD. Three-way crosses (TC) provide an opportunity to incorporate desirable genes from the grand parents into the well-adapted genetic complex already present in the genotype of the third parent. In the F_1 generation of a TC, a population of 250 to 300 plants was raised and plants were selected for desirable appearance and some attributes provided by the grandparents, such as larger seed size, more seeds per pod, and branching pattern (all highly heritable characters). In the TCF_2 generation, single-plant progenies in two orthree-row plots were planted with the third parent as check in every fourth or fifth plot. Evaluation and selection among these progenies in comparison with the third parent permits selection for desirable gametes from the parental single cross.

Table 3. Performance of some early ICRISAT lines and composite populations at Hissar, 1979.

Entry	Days to 50% flower	100-seed wt (g)	Yield (kg/ha)
EACT			
ICPL-86	70.0	8.5	2126
ICPL-87	75.0	10.2	2264
Prabhat (check)	69.0	6.3	1663
UPAS-120 (check)	78.0	7.9	1817
LSD	3.0	0.62	507
Test-3			
5 lines	68-74	8.5-11.4	2057-2238
Comp. IDT	66.0	8.2	1786
Prabhat (check)	68.0	6.8	1286
LSD	3.1		435
Test-5			
2 lines	61-67	8.1-9.7	2005-2305
Comp. IIDT	67.0	8.6	2057
Prabhat (check)	65.0	6.4	1490
LSD	1.9		360

TC F_2 progenies are actually individual F2 populations. The question has been raised often regarding the adequacy of the population size being grown in two or three row plots, and the utility of selection of individual plants in the TC F1 generation. Three-way crosses have been used in several national and international programs but details of handling them in segregating generations are not available. Our experience shows that if TC F1 plants are selected as close as possible to the third parent in general appearance and maturity, and in addition for some highly heritable attributes contributed by the grandparents, the TC F2 progenies are strikingly uniform. The TC (Prabhat x ICP-8503) x ICPL-10 is a good example. In this cross, selection for the earliness of Prabhat and the large seed size and the greater seed number (more than six seeds per pod) of ICP-8503 has been highly effective in developing a large number of very uniform TC F2 progenies with these attributes, even though Prabhat and ICP-8503 differ in many traits.

Accumulation and fixation of genes with additive gene action from the three parents for the characters of interest in TC F1 and selection for them probably explains the apparently reduced segregation and variability in these progenies. Thorne et al. (1970) indicated substantial gene fixation for yield in the F2 generation of soybean crosses. Differences among lines within a family have been found to be less important than among lines from different families (Mahmud and Kramer 1951; Voigt and Weber 1960).

Bulk Hybrid Advance

SINGLE-POD DESCENT. AS an adaptation of the single-seed descent (SSD) method (Brim 1966), we have advanced a large number of populations by growing approximately 4000 F2 plants, harvesting a single pod from each plant. This seed is all planted and thinned to a stand of 4000 plants in the next generation. These populations have been planted late (August or September) in order to reduce plant size and telescope flowering dates, thus avoiding severe competition that might eliminate the earliest segregates.

While SSD was suggested for self-pollinated crops, the cross-pollination in pigeonpea could result in the loss of extreme segregates through intermating and regression to the mean and failure to fix sufficient homozygosity for effective selection.

To determine the extent of variability in different generations of unselected advanced populations, a test consisting of three generations (F_2, F_3, and F_4) of the crosses HY-3C X Prabhat, UPAS-120 x ICP-7086, ICP-1 x NP (WR)-15, and ICP-7086 x ICP-7035 was planted in 1978 as a split-plot test in a lattice square design. The crosses weretreated as main plots and thethree generations plus one pure check cultivar as subplots. The range and variances for days to flower, pod and seed color, plant type, growth habit, seeds per pod, seed size, and yield indicated that there was no recognizable decline in the variability for these characters.

Another test was conducted to determine the frequency of homozygous individuals for various characters within a population in Fs. To develop the Fs populations about 1000 individual plants were harvested from each of two unselected F_4 bulk advanced populations. In 1978 these plants were grown at two locations in two-row plots. All progenies were scored 1 to 5 for visual uniformity, 1 being highly uniform and 5 highly variable. Twenty-eight progenies at Hyderabad and 64 at Gwalior were scored 1 — about 3 and 8% of the progenies, respectively. At Hyderabad, 20 progenies scored 2 for uniformity were also selected for advancing. For each of the selected progeny, one pod from each plant was harvested to plant individual plant-progeny hills in two rows for further purification and maintenance of the progeny by selfing only similartype plants in each progeny. Also, progenies were bulk harvested for yield testing along with check cultivars in replicated tests of four-row plots at the respective locations. Distribution of yields of the 48 lines tested at ICRISAT Center is shown in Figure 2. Selected progenies will be further evaluated using selfed seed from thepurification block and lines saved will be purified and maintained by selfing.

These observations suggest that bulk population advance by single-pod descent can be a practical approach in pigeonpea breeding, where a large amount of individual plant selfing and evaluation in early generations can be avoided. The steps involved are:

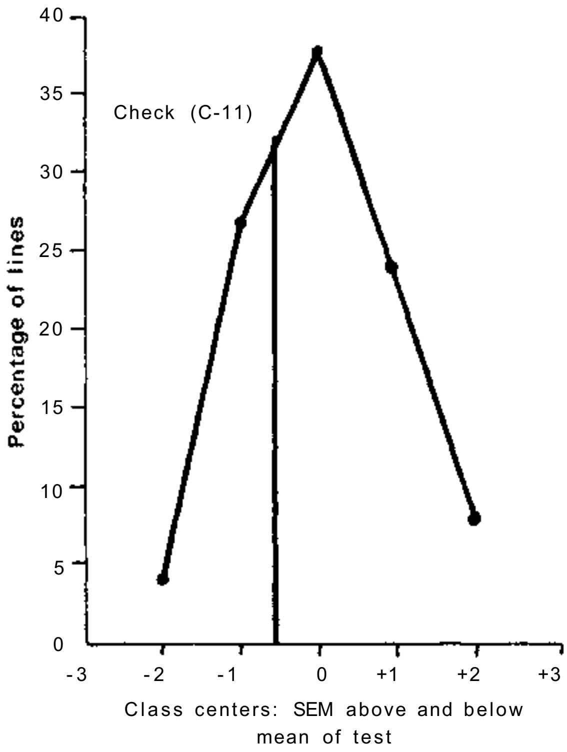

Figure 2. Distribution of yields of 48 F_4 *derived lines of C-11 x 6997 selected for uniformity in Fs and tested at ICRISA T Center in* F_6 *in 1979.*

1. Advance populations of selected crosses to F_4 by single-pod descent with about 4000 plants planted in each generation in an approximately square block to minimize contamination by outcrossing from adjacent populations.
2. In F_4 harvest 1000 individual plants for planting F_5 progenies.
3. Plant 1000 Fs progenies in two- or three-row plots, with every fourth or fifth plot a check cultivar.
4. Score the progenies for desirability and uniformity, and harvest progenies scored 1 and 2, recording yield as percentage of the closest check plot.
5. In Fs evaluate the progenies for yield, either with close checks or in replicated yield tests, depending on the number of progenies to be evaluated. Retest the best progenies in the next year.

6. Start selfing and purification simultaneously with the progeny evaluation in F_6 and onward.

MASS SELECTION. Wide variation for morphology and yield components, including pod number, number of seeds per pod, and seed size has long been recognized (Mahta and Dave 1931). In view of the extent of outcrossing and the fact that most landraces contain considerable variability, Howard et al. (1919) recommended mass selection as the best breeding method. However, only limited data on mass selection for yield have been published.

Using a grid system where the two highest yielding plants in a 10-plant subplot were selected, two hybrid populations were mass selected for two generations when intercropped with maize. Failure to change either mean or variance was reported earlier (Green et al. 1979). Our conclusion was that plant-to-plant variance in pigeonpea is largely environmental, resulting in ineffective selection for yield on a single-plant basis. This has been discussed above under pedigree selection.

Population Breeding

Given the fact of natural outcrossing in pigeonpea, two dual population schemes (Rachie and Gardner 1975) were initiated, utilizing obtuse leaf in one and determinate plant type in the other as the recessive markers. The initial populations were F_2S of several parents crossed with two obtuse leaf lines to form one population and the second by crossing a determinate parent, Pusa Ageti, with 26 indeterminate parents. In alternate generations the recessive marker plants only were harvested; heterozygous plants showing the dominant trait were harvested in the other generations. These populations have been continued since 1975. Individual plants were harvested in 1980 to derive lines for determining variance in the populations.

More recently, populations involving genetic male sterility have been developed. In these, three populations are being maintained; in one, bulked seed from only male-sterile plants is harvested and replanted, in the second, bulked seed from only fertile plants is replanted, and in the third, bulked seed from both male-sterile and fertile plants is replanted. Lines will be derived to test the variance of the three populations.

On the basis of our experience with individual plant selection, we do not try to apply selection pressure for yield to these populations. When lines are derived for evaluating the populations and for selection, we expect to yield test S2 lines in order to assure enough seed for adequate testing.

Influence of Cropping System on Selection

Breeders have traditionally selected in pure stands of pigeonpea, in spite of the fact that the crop is usually grown as an intercrop. In recent years the utility of selection under pure cropping for obtaining genotypes performing well in intercropping has been questioned. Fyfe and Rogers (1965), Harper (1967) and Dijkstra and De Vos (1972), working with pasture legumes and grasses, have stressed that varieties that are expected to perform in mixtures should be bred specifically for that purpose. However, in mixtures of pasture legumes and grasses the two species are competing during a limited favorable growing season and under grazing. The results obtained from those studies may not necessarily be applicable to two species grown in association, with dissimilar growth patterns such that competition between the two is minimal at the critical crop growth stages. Francis et al. (1978) observed that yields of *Phaseolus* bean in monoculture and intercropped with maize were highly correlated. They concluded that the higher yields and greater differences among cultivars in monoculture favor selection and yield testing.

The medium-maturity pigeonpea germplasm selectionsweretested in sole and intercrop with sorghum in adjacent experiments in 1976-77, and in split-plot design the following 3 years (Table 4). In these tests it was possible to evaluate cultivar response to cropping system within a given environment. Scatter diagrams for the 4 years' tests (Figure 3) indicate some linearity of relationship of yields between the two systems. Included in the diagrams are only those cultivars of medium maturity, adapted to the ICRISAT Center environment.

If cultivars are developed primarily for intercropping, the question to be answered concerns the relative effectiveness of selection in

Table 4. Results of selection in medium-maturity pigeonpea at 20 and 33% levels in sole crop and cereal intercrop at ICRISAT Center on Vertisol.

		Number of lines				
Year	Intercrop	In test	20% selected	Common	33% selected	Common
1976-77[a]	Sorghum	36	7	2 (29%)	12	5 (42%)
1977-78	Sorghum	17	3	2 (67%)	6	5 (83%)
1978-79	Sorghum	19	4	3 (75%)	6	5 (83%)
1979-80	Sorghum	14	3	0(0%)	5	1 (20%)
Totals		86	17	7 (41%)	29	16 (55%)
1977-78	Maize	11	2	1	4	1
1978-79	Maize	19	4	1	6	3
1979-80	Maize	20	4	1	7	5
Totals		50	10	3(30%)	17	9 (53%)

a. Genotyplc differences were significant in all the years except 1977-78.

pure crop for intercrop performance. In Figure 3, the cutoff for 20% selection in each cropping system is shown. In Table 4 the figures are given for both 20 and 33% selection, indicating the number of lines selected in common in both cropping systems. There are apparent year effects, for in 4 years the percentage selected in common by the two systems ranged from 0 to 83%. On an average over 4 years, selection in pure crop would have been 41% effective at 20% and 55% effective at 33% selection intensity for picking the top 20 and 33% in intercrop performance.

The history of individual selections can be traced through the 4 years as a further evaluation of effect of cropping system on selection. Sel. 185-9 had the highest average pure-crop yield over 4 years. In 3 of 4 years, it was in the top 20% in pure crop, while in only 1 year of 4 was it in the top 20% in intercrop. Sel. 2223-3 had the highest intercrop average yield. It was in the top 20% 3 years, and in the top 33% the other year in intercrop. In the pure crop it would have been selected inthetop 20% 2 years, in the top 33% 3 years.

In the lower half of Table 4, comparison of selection pressure in pure crop and maize intercrop at 20 and 33% also shows a differential response for cultivars. These trials were not contiguous, but in different fields, so comparisons might not be so meaningful as those reported in the upper part of thetable. However, selection in pure crop would have been 53% effective for intercrop performance, agreeing closely with the observation above.

While the data are not extensive, they consistently show that relative yields in sole and intercrop are not identical. Considering the low heritability of yield and genotype x year interactions, we recommend mild selection in the first year of yield testing. However, with 33% selection, only 55% of the highest yielding entries in intercrop with sorghum would have been selected from the pure crop. From the viewpoint of efficiency of selection only, it appears essential to select in the target environment. While the ICRISAT breeding strategy for yield is to select among advanced derived lines from unselected advanced generation bulks, in programs where earlier selection is practiced, it would be beneficial to plant early generation material in the intercrop for which it is being developed, to take advantage of natural selection pressures.

Hybrid Pigeonpeas

ICRISAT has developed a technology for the production of hybrid seed. We are utilizing a genetic male-sterile to provide the mechanism for crossing a female line with a pollinator line. We have, to date, demonstrated the feasibility of producing crossed seed using varying proportions of male and female rows. This genetic

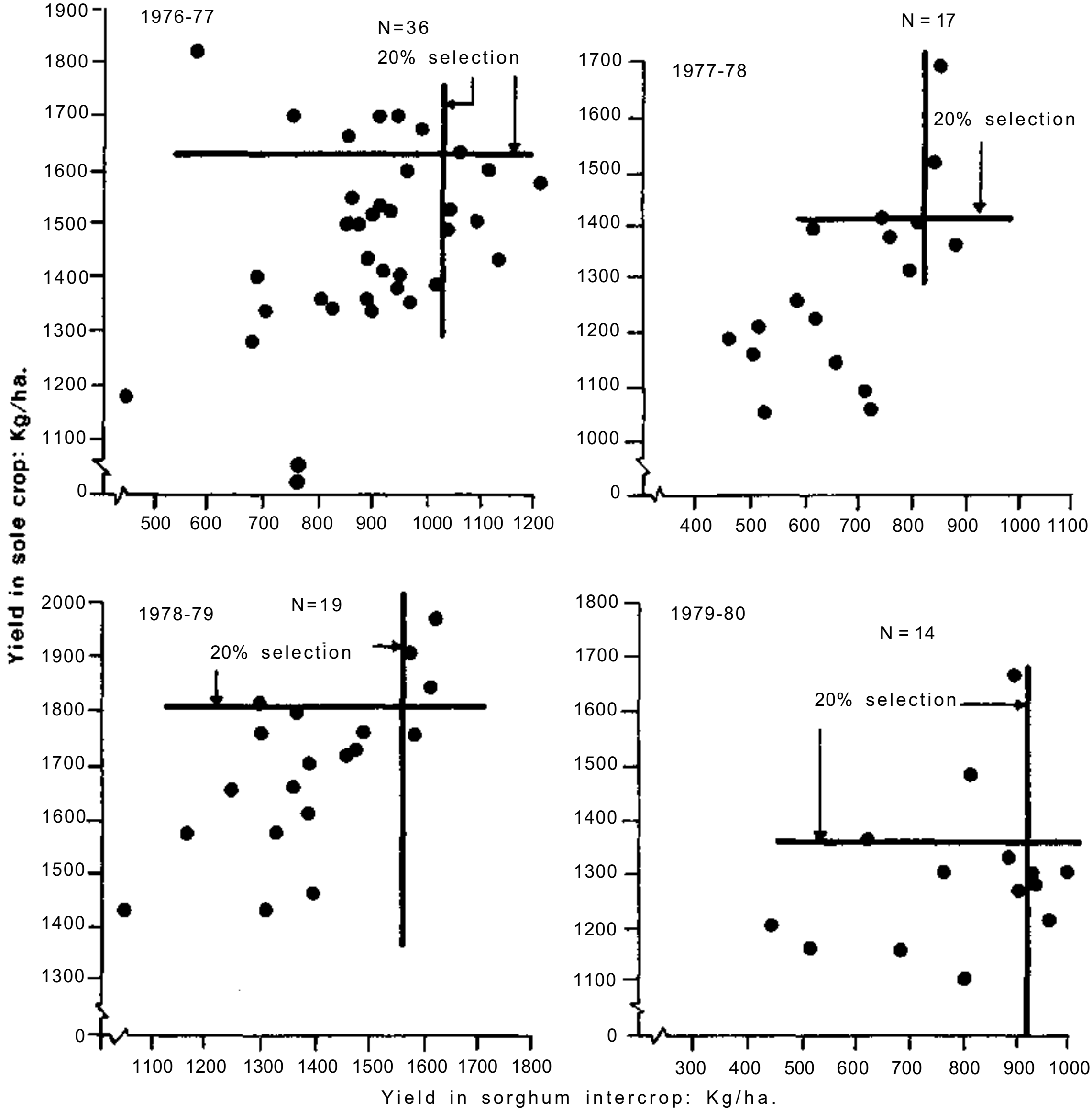

Figure 3. Distribution of yields of lines in pure crop and intercrop in adjaceint trials (1976/77) and in split plot trials (1977-1980).

male sterility system requires roguing 50% of the normal fertile plants from the female rows in the hybrid seed production blocks and identification and collection of seed from the male-sterile plants in the maintenance block. These operations represent the primary additional expense involved in the production of hybrid seed vs production of seed of ordinary varieties.

So far only a limited number of hybrids have been developed and tested at ICRISAT. Based on studies that generally show additive gene action in pigeonpea, we would expect to find most hybrids with no superiority over the highestyielding cultivar. However, such studies also indicate some specific combining ability, and successful hybrids will result from those combinations where genetic effects result in considerable heterosis in the F_1, To find these combinations and develop a successful hybrid program, it will be necessary to test a large number of hybrids.

During 1979-80, four stations were designated by ICAR to work on pigeonpea hybrids. Two commercial companies have also undertaken programs to develop hybrids. ICRISAT has not undertaken a full-scale hybrid breeding program because it falls outside our main mandate. However, the existence of a hybrid seed production technology does not reduce the need for conventional breeding, since if hybrids are successful, their success will depend on the continued development of better parent lines. For this reason we continue to devote most of our resources to the development of the improved breeding populations from which local breeders can derive better lines.

We are backcrossing the male-sterile gene into several cultivars of different maturity, and are adding disease resistance to existing sterile lines. We are also searching for useful cytoplasmic sterility.

Breeding for Disease Resistance

Breeding for disease resistance mainly involves pedigree selection either from straight crosses or from backcrosses involving resistant parents. From the F_3 onward, selection is first done on the basis of disease incidence within a progeny or family in relation to the susceptible check genotype planted intermittently. Then, depending on the number of selected progenies, either five plants per progeny or all plants in a progeny are selfed. Single plants selected from progenies showing a high level of survival for 2 or 3 years are evaluated for yield in progeny rows with frequent check plots. They are also retained in the appropriate disease nursery for checking for resistance. In these nurseries they are maintained by selfing.

The system has been quite successful for identifying resistant genotypes for sterility mosaic disease and stem rot (*Phytophthora drechsleri* f. sp. *cajani,* P2), where genetic control of resistance is simple. However, for identifying genotypes resistant to wilt *(Fusarium udum),* success has been mainly confined to establishing pure lines with dependable resistance either from already known sources of resistance, including NP (WR)-15, C-11, BDN-1, 15-3-3 and KWR-1, or from new germplasm lines. There has been very slow progress in establishing wilt-resistant lines from crosses between a resistant source and a susceptible agronomically desirable genotypes. There could be three reasons for this: (1) lack of purity or uniformity of the resistant parents used in crosses, (2) complex inheritance based on multiple genes, and (3) a high degree of variability for virulence in the wilt pathogen.

Under these circumstances, it appears that for incorporating wilt resistance, backcrossing to the resistant parent and selecting for highly heritable characters, including yield components and/or resistance to sterility mosaic and/or stem rot, from the donorpa rent would be most productive. A backcross program to incorporate sterility mosaic resistance in BDN-1, a cultivar resistant to wilt and stem rot, is in the third back-cross, and progenies appear promising.

Multiple Disease Resistance

For stability of yield and wide adaptability of genotypes in India, it is essential that cultivars be developed with resistance to the three diseases, wilt, sterility mosaic, and stem rot In the long run, developing dependable resistance to the three diseases will depend on finding genes for resistance to different races of the diseases. However, at present it seems desirable to use in a crossing program aimed at developing multiple disease resistance, both the parents carrying wilt resistance while, in addition, one of the parents carries resistance to sterility mosaic virus and the other to stem blight. This is because screening progenies of crosses with only one wilt-resistant parent in the multiple-disease nursery has not given promising results. It is encouraging to note that we have available a number of agronomically desirable genotypes with a good level of wilt resistance. These can be utilized in developing multiple-disease resistant lines step by step.

Conclusions

We have reported here some of the findings of the ICRISAT pigeonpea breeding program, with particular emphasis on methodology. Some important conclusions are: (1) Photoperiod-responsive pigeonpea (the normal type) should be selected and tested in the environment in which they are to be utilized. (2) Single-plant selection for yield is generally ineffective; selection must be done on a progeny basis. (3) Local landraces are a good source for making selections; breeders in national programs should derive lines from the local landraces to identify high-yielding locally adapted lines for use in breeding and/or for release. (4) Selection among lines derived from advanced bulk hybrid appears to be more efficient than pedigree selection in breeding for yield. (5) Pedigree selection is useful in breeding for highly heritable disease resistance and yield components; early maturity lines with increased seed size and seed *number* per pod have shown superior yielding ability. (6) F_1 hybrids have potential for increasing production, but intensive work at the local level is necessary to identify the best combinations suitable to different agroecological regions.

References

BELL, G. D. H. 1963. Breeding techniques. Pages 285-306 *in* Barley Genetics 1. Wageningen, The Netherlands: Pudoc.

BRIM, C. A. 1966. A modified pedigree method of selection in soybeans. Crop Science 6: 220.

BUSCH, R. M., JANKE, J. C, and FROHBERG, R. C. 1974. Evaluation of crosses among high and low yielding parents of spring wheat and bulk prediction of line performance. Crop Science 12: 856-859.

BYTH, D. E., GREEN, J. M., and HAWTIN, G. C. 1980. ICRISAT/ICAROA chickpea breeding strategies. Pages 11-27 *in* Proceedings, International Workshop on Chickpea Improvement. ICRISAT, 28 Feb-2 Mar 1979, Hyderabad, India.

DE PAUW, R. M., and SHEBESKI, L. H. 1973. An evaluation of an early generation yield testing procedure in *Triticum sativum.* Canadian Journal of Plant Science 53: 465-470.

DIJKSTRA, J., and DE vos, A. L F. 1972. The evaluation of selections of white clover (*Trifolium repens* L.) in monoculture and in mixture with grass. Euphytica 21:432-449.

FASOULAS, A. 1973. A new approach to breeding superior yielding varieties. Department of Genetics and Plant Breeding, Aristotelian University of Thessaloni Pub. No. 3. Thessaloni, Greece.

FRANCIS, C. A., PRAGER, M., and LAING, D. R. 1978. Genotype x environment interactions in climbing bean cultivars in monoculture and associated with maize. Crop Science 18: 242-246.

FREY, K. J. 1971. Improving crop yields through plant breeding. Pages 15-58 *in* Moving off the yield plateau. American Society of Agronomy Special Publication 20, Madison, Wis, USA.

FREY, K. J. 1972. Stability indexes for isolines of oats *(Avena sativa* L). Crop Science 12: 809-812.

FYFE, J. L., and ROGERS, H. H. 1965. Effects of varying variety and spacing on yields and composition of mixtures of lucerne and tall fescue. Journal of Agricultural Science 64: 351-359.

GREEN, J. M., SHARMA, D., SAXENA, K. B., REDDY, L. J., and GUPTA, S. C. 1979. Pigeonpea breeding at ICRISAT. Presented at the Regional Workshop on Tropical Grain Legumes, University of the West Indies, 18-22 June, 1979, St. Augustine, Trinidad.

HAMBLIN.J. 1977. Plant breeding interpretations of the effects of bulk breeding on four populations of beans *(Phaseolus vulgaris* L.). Euphytica. 26: 157-158.

HARPER, J. L. 1967. A Darwinian approach to plant ecology. Journal of Ecology 55: 247-270.

HARTWIG, E. E. 1972. Utilization of soybean germplasm strains in a soybean improvement program. Crop Science 12: 856-859.

HOWARD, A., HOWARD, G. L. C, and KHAN, A. R. 1919. Studies in the pollination of Indian crops. I. Memoir, Department of Agriculture, India (Bot. Ser.) 10: 195-220.

KNOTT. D. R. 1972. Effects of selection for F_2 plant yield on subsequent generations in wheat. Canadian Journal of Plant Science 52: 721-726.

KNOTT, D. R. 1979. Selection for yield in wheat breeding. Euphytica 28: 37-40.

MAHMUD, E., and KRAMER, H. H. 1951. Segregation for yield, height and maturity following a soybean cross. Agronomy Journal 43: 605-608.

MAHTA, D. N., and DAVE, B. B. 1931. Studies in *Cajanus indicus.* Memoir, Department of Agriculture, India (Bot. Ser.) 19: 1-25.

MCGINNIS, R. C, and SHEBESKI, L. H. 1968. The reliability of single plant selection for yield in F2. Third International Wheat Genetics Symposium: 109-114.

RACHIE, K. 0., and GARDNER, C. 0. 1975. Increasing efficiency in breeding partially outcrossing grain legumes. Pages 285-297 *in* Proceedings, International Workshop on Grain Legumes. ICRISAT, 13-16 Jan 1975, Hyderabad, India.

SHARMA, D., and GREEN, J. M. 1975. Perspective of pigeonpea and ICRISAT's breeding program. Pages 19-29 *in* Proceedings, International Workshop on Grain Legumes. ICRISAT, 13-16 Jan 1975, Hyderabad, India.

SNEEP, J. 1977. Selection for yield in early generation of a self-fertilizing crop. Euphytica 26: 27-30.

THAKRE, R. B., and QUALSET, C. 0. 1978. Empirical evaluation of single-plant and family selection strategies in wheat. Crop Science 18: 115-118.

THORNE, J. C, WEBER, C. R., and FEHR, W. R. 1970. Character fixation and its relationship to F2-derived line method of soybean breeding. Iowa State Journal of Science 44: 271-278.

THORNE, J. C, and FEHR, W. R. 1970a. Incorporation of high protein exotic germplasm into soybean populations by two- and three-way crosses. Crop Science 10: 652-655.

THORNE, J. C, and FEHR, W. R. 1970b. Exotic germplasm for yield improvement in 2-way and 3-way soybean crosses. Crop Science 10: 677-678.

VOIGT, R. L, and WEBER, C. R. 1960. Effectiveness of selection methods for yield in soybean crosses. Agronomy Journal 52: 527-530.

Adaptation and Breeding Strategies for Pigeonpea

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Abstract

Breeding objectives and strategies appropriate to different production systems will be discussed. The discussion will include definition of existing and potential cropping systems, methodology, international cooperation in breeding and environmental adaptation.

In this workshop, we have been exposed to numerous papers that have considered various aspects of the production, improvement, and use of pigeonpea internationally. This paper is intended to take a more general overview of the adaptation of the crop and its influence on breeding strategies in plant improvement. With certain exceptions, we will not consider specific breeding methodology.

Pigeonpea is grown under a wide range of cropping systems internationally. This is due in part to the diversity of the environments of production, the genotypes available, the perception of the role of the crop in rotations, and the end use of the product. Some applications of the crop are of traditional origin and have been incorporated into rather rigid concepts of land use that have rather doubtful contemporary relevance but may be difficult to change. Other applications are recent innovations. The development of scientific agriculture and plant improvement and the changing demands for food may force changes in the form or importance of these systems. At present, however, these systems are in wide use regionally and therefore must be considered in plant improvement.

The great diversity of habit and use of pigeonpea make its improvement a most complex and interesting challenge. As for most of thetropical and subtropical grain legumes, little formal plant improvement has been attempted in pigeonpea compared with the major cereal crops, and this implies that relatively large genetic improvements in production can be attained rapidly. However, it is imperative that plant improvement addresses the real problems of the production systems; that is, that the systems are identified and described, that research is designed and conducted in the most effective manner to make advances in production within each of those systems, and that new production systems are developed to both improve existing production and expand the adaptation of the crop. Accomplishment of these objectives is complicated by the relatively poor scientific knowledge of the crop, its range of ecophysiological adaptation and use, and the canalized approach to improvement of the traditional systems per se.

The Production Systems

As in most of the tropical and subtropical grain legumes, phenological response as influenced by photoperiod and temperature is the primary plant function involved in the ecophysiological adaptation of pigeonpea. These aspects have been considered elsewhere in this workshop. In brief, however, *Cajanus cajan* exhibits a range of photoperiodic response from day-neutrality (Turnbull, personal communication) to quantitative short-day behavior. Most genotypes show the latter response, and a wide range of flowering times exists (Green et al. 1979). Temperature influences onset of flowering in early-maturing, photoinsensitive material

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(Turnbull et al. 1981), and photoperiod x temperature interactions affect the phenology of many genotypes.

Since phenology underlies the development of production systems, knowledge of its effects and control is important in plant improvement. Various authors (Spence and Williams 1972; Wallis et al. 1979a) have reported the use of so-called "physiologic dwarfing" in shortening daylengths to reduce crop duration and biomass. The influence of phenology x plant density interactions on production in soybean was discussed by Lawn et al. (1977), and the same general principles apply to pigeonpea (Wallis et al. 1979a).

Maturity group classifications have been established in pigeonpea (Green et al. 1979). For convenience, we have reduced the diversity of production systems to three general classes. These are based on phenology, and the classification is justified on the general similarity of plant growth and development within a phenological class, and the differences between classes. We define the classes as: long-season crops, full-season crops, and short-season crops.

Long-season Crops

This classification is considered to include those crops sown at or around the longest day of the year, in which generally flowering occurs after the shortest day of the year. This is the traditional system in north India and parts of central India. Commonly, the crop is sown at low density in June-July, grows vegetatively throughout the monsoon season, flowers around January, and is harvested in March-April. Such crops produce massive vegetative growth, and are almost invariably intercropped. They are generally restricted to frost-free areas and heavy soils of high water-holding capacity.

Full-season Crops

Production systems that utilize the entire length of the warm season are included here. They are earlier maturing than the long-season crops at the same sowing date, with sowing at or around the longest day, flowering in decreasing daylengths, and harvested after the normal sowing time of winter crops. In some situations intercrops, ratoon crops, or rotations with a short-season spring-sown crop may be possible. Examples include cv Royes cropping systems in Australia (Wallis et al. 1979a) and the common cropping system in Maharashtra, India, utilizing BDN-1 maturity material.

Short-season Crops

Two distinct subclasses of this production system are defined.

Early-maturing Crops

This subclass involves sowings made 2 or more genotypes insensitive, or nearly so, to photoperiod, which mature quickly regardless of sowing date; for example, Prabhat and UPAS-120 for June- July sowings in north and west India, which are harvested prior to normal sowing of winter crops, and sowings at different times of the year for phtoinsensitive material (Wallis et al. 1979b). Such crops have been ratooned successfully in favorable environments.

Off-season Crops

This subclass involvee sowings made 2 or more months after the longest day, so that crop duration is relatively short. Such crops are possible only where winter temperatures are favorable, for example, September-October sowings in Bihar, India, and March sowings in Fiji. Due to rapid floral induction conditioned by short days, both photoperiod sensitive and insensitive genotypes may be used in this system. However, only insensitive material can provide subsequent short-season ratoon crops. Flowering in photosensitive genotypes will be delayed by the increasing daylength prevailing during ratoon growth.

These production systems are diagrammed in Figure 1, with respect to days after the longest day. Generalized distributions of photoperiod, temperature, and moisture availability likely to occur in a monsoon environment are also depicted. This classification is general and will not explicitly identify all production systems. However, it is a pragmatic basis on which to consider breeding strategies. An understanding of the nature and diversity of crop adaptation is a prerequisite to plant improvement in any crop.

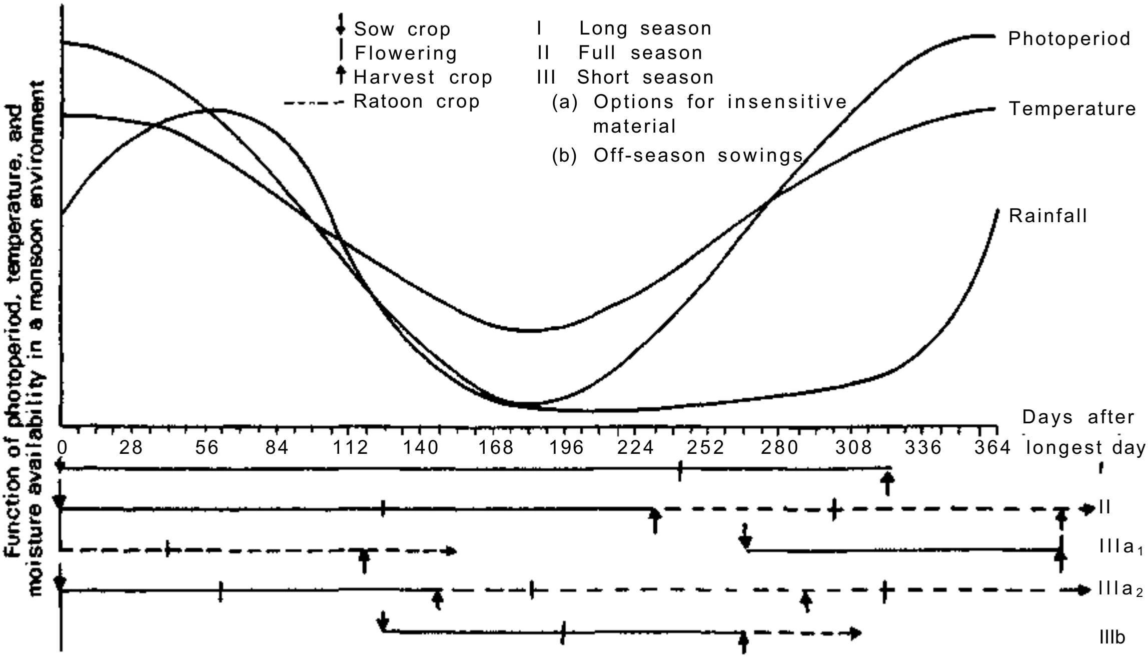

Figure 1. Generalized classification of production systems in pigeonpea.

Since phenology is the central issue in the adaptation of most grain legumes (including pigeonpea), it is used as the basis of classification.

Some Problems Underlying Improvement of Pigeonpea

Plant improvement is a multidisciplinary activity concerned with the optimization of genetic attributes within the constraints of the environment, and of environmental factors within the constraints of the genetic material. Since performance is the integral of genetic and environmental influences, maximum improvementwill result from joint advance in both areas. However, unilateral improvements in areas of particular limitation can have major impact.

In all crops, the scientist must confront particular problems, as distinct from objectives, in establishing effective plant improvement. Some problems are general across crops; others are crop-specific. In this section, we discuss some problems in pigeonpea improvement.

Stratification of Plant Improvement Based on Phenological Response

In all crops, the nomination of clear objectives with respect to the general adaptation of the crop is an integral part of plant improvement, and should precede consideration of specific improvements. This is particularly so in pigeonpea, since there are greater differences in growth and development among the various production systems than there are between many other crops. This implies that quite different physiological limitations will exist in material adapted to the different systems. Further, it is probable that expression of genetic variability, inheritance, and heritability for particular characters, and the interrelationships among them, will also be different. Thus, improvement within the different systems will pose quite different physiological and genetic problems, and requires independent study. Some objectives will be common across systems, but attainment will require discrimination on response to the specific challenges of each system. Significant transfer of genetic advances across systems is possible, e.g., insect and disease resistance, and a clear case for centralized research exists for such cases.

Thus we consider that quantitative pigeonpea improvement should involve identification of the major production systems in use or of potential value, determination of their comparative relevance in an area, and implementation of breeding specifically within and for the optimal system. The simple transfer of breeding lines between systems can be useful but it is not considered a satisfactory general basis for improvement.

As indicated previously, phenology is the primary factor in the ecophysiological adaptation of pigeonpea. Most genotypes are quantitative short-day plants, and phenology is also influenced by complex temperature interactions. Since production systems are designed to satisfy constraints imposed by the environment (start and end of a wet season, seasonality of insect attack, etc.) or by management (rotation of crops, availability of irrigation, etc.), phenological response provides a convenient and consistent method of scheduling crop development. This can be exploited to complement the breeding effort, using routine agronomic evaluation and rigorous truncation on phenology. The constraint of a breeding program to a particular phenological group may predispose to a narrowing of the genetic base. However, considerable genetic variability for most characters is available throughout the phenological range of pigeonpea, and introgression of genetic material from other production systems can be practiced as necessary.

We see no clear justification for attempting to develop photoperiod-insensitive material for long- or full-season production systems. However, there is a need for short-season material to service other production systems, i.e., *rabi* (postrainy season) sowings, spring sowings, and summer sowings. Short-season crops can be generated either by growing normally long-season material in photoperiods shorter than the critical daylength (rabi sowing) or by development of material insensitive (or nearly so) to the daylengths experienced in that region. The latter approach is necessary to attain short-season crops during periods of long days. Since photoinsensitivity can provide relatively stable phenology across sowing dates at a site and across latitudes, it is more generally applicable and is to be preferred in the breeding of pigeonpea for short-season culture. Studies at the University of Queensland indicate that many lines which flower in 65 days or less from sowing under the longest day-lengths at 28°S, are insensitive or nearly so to 16-hour days (Wallis et al. 1981a). Thus a simple selection screen in the field can be used to identify genetic material that will produce short-season crops at any latitude between about 35°N and 35°S latitude. Regional screening would be necessary to determine the effects of temperature on phenology and for other breeding objectives. However, a methodology clearly exists by which local breeding for short-season culture under long-day conditions can be implemented. Because of genetic insensitivity of this material, introgression across regions, latitudes, and management systems presents relatively few difficulties. Introgression between the short-season and other cropping systems is considered in a later section of this paper.

Thus we consider that it is necessary to establish individual pigeonpea improvement programs based on particular production systems. Phenological response is a sensible basis for this truncation because it is more generally applicable over latitude and sowing date than existing classifications into early, medium, and late maturity groups. Local breeding would specialize in one or more relevant systems. Valuable contributions by centralized plant improvement programs could be made in three main areas, namely, development of breeding populations and lines specifically adapted to particular systems, introgression of genes among the genetic bases of these systems, and the improvement of characters that are transferable across production systems (such as disease and pest resistance).

Agronomic Knowledge of the Production System

The relative potential of particular production systems in a region can be predicted by modeling crop adaptation on the basis of known or imputed limitations of the environment and of the genetic material. However, the usefulness of the prediction depends on the adequacy of the model used. Thus the ultimate test of relevance is an empirical evaluation. This needs to be a continuing exercise because of change in the environment, management, genetic material, needs, and perceptions of adaptation.

Regardless of the system traditionally used or adopted, a detailed understanding of the factors limiting plant growth and development is necessary in order to define optimal agronomic systems and relevant objectives in improvement.

In pigeonpea, the understanding is confounded by the complexity of cropping systems, traditional use under generally low-input marginal conditions, and the relatively low level of scientific knowledge of the plant. Simply, the crop is underresearched, and it is doubtful that objective decisions can be made today regarding the relevance of particular production systems, let alone (with few exceptions) the specification of limitations within those systems. Clear definitions of tangible breeding objectives requires a detailed understanding of crop adaptation and plant growth and development. This is not available for many pigeonpea production systems.

While the existence of traditional systems of use must be respected and actions taken to improve their effectiveness, potentially more efficient systems must be actively researched. These may require management inputs, such as the use of fertilizer or agricultural chemicals, which are currently considered infeasible or uneconomic. The value of such inputs can only be determined experimentally within otherwise optimum systems, and it is a responsibility on researchers to approach the problem objectively. To prejudge this issue without evidence is to restrict pigeonpea to a useful but marginal role agriculturally. Recent evidence (Wallis et al. 1979a, 1979b) clearly indicates that the crop is capable of high seed yield under improved management. Breeding must exploit this ability of the crop, as well as its tolerance of marginal conditions.

Intercropping of pigeonpea is a useful production practice in some situations, but its improvement for such systems presents considerable additional problems in experimental design, selection, and evaluation. The relevance of intercropping systems and demonstration of genetic advances for them can only be relative to optimal monocrop production. In view of the complexity of the problem and of the large production advances possible in monocrop as a result of genetic and agronomic manipulation, breeding specifically for intercrop adaptation is not justified at this time. Screening of improved genotypes under intercropping may be adequate.

Regardless of the cropping system in use, a clear understanding of its potential to produce and of its genetic and environmental limitations is a prerequisite to definition of realistic breeding objectives. This implies that optimal agronomic (sowing date, density, arrangement) and management inputs need to be determined. Breeding objectives defined and researched under suboptimal management may be totally irrelevant or even counterproductive under improved management. Conversely, simple cultural changes may create different limitations and thus new breeding objectives. There is clear evidence that large increases in production can result from improved agronomy and management. This approach to improvement should be exploited prior to commitment of significant resources to breeding. This is true for both monocrop and intercrop systems.

In any crop improvement program, the level of management input appropriate in the breeding phase is open to debate, and ranges from optimal management to average farmer technology. The question is complex and data do not exist for pigeonpea to provide any guidance. However, we consider that cultural inputs are simply study tools for a purpose, and should be used as such in applied research. The basic objective of breeding is to identify genetic differences, and effective discrimination is prejudiced by any factor that reduces genetic expression or increases error. Thus precise experimentation is critical particularly with respect to the use of uniform test sites and the attainment of appropriate and uniform plant populations. Testing in uncontrolled and erratic environments across sites and years elicits genotype x environment interactions that confound selection. In breeding for insect and disease resistance, this means the use of controlled or augmented pest/pathogen populations. For quantitative characters, it is pointless to attempt selection in conditions so adverse that little or no genetic variation can be detected. This does not imply use of nonlimiting test regimes, but it does mean the use of adequate environmental management such as supplemental irrigation, crop protection, etc., to avoid stresses that will confound discrimination, particularly during the selection phase. Subsequent evaluation of selections under "farm" conditions is critical, and this will indicate the validity of the selection strategies imposed in breeding.

Reproductive Biology and Growth Habit

Certain aspects of the biology of pigeonpea create difficulties in the conduct of plant improvement. Two of these are the long crop duration of many genotypes, and the mating system.

As indicated previously, phenology is a function of photoperiod response and photoperiod x temperature interaction. Prolonged vegetative growth extends the generation interval and creates larger plants, which create difficulties with population sizes- and rate of generation turnover.

The system of mating has basic implications for the genetic structure of populations and the conduct and strategy of plant improvement. Substantial natural outcrossing by bees can occur in pigeonpea. This creates significant problems in breeding and in pure seed production for experimentation and commerce. Development of breeding methods appropriate to the mating system, and decisions on the type of cultivar to be used, are necessary. Modification of the mating system itself is a valid objective in breeding.

Aspects of Breeding Strategy

Impact of Mating System on Breeding System and Cultivar Form

Outcrossing of pigeonpea, mainly by bees (Pathak 1970), can exceed 50% under some circumstances. As a result, controlled production of self-pollinated seed by bagging is necessary for genetic testing and maintenance. This is costly in time and resources, and results in limited seed increase. It is notgenerally feasible in routine breeding, and the use of open-pollinated seed for progeny tests creates problems. Similarly, isolation for large-scale pure seed production of cultivars and advanced lines is rarely possible in India, with the result that commercial seed and advanced lines generally are highly heterogeneous. This negates much of the data derived from regional pigeonpea trials.

Thus natural outbreeding in pigeonpea imposes considerable costs and inefficiencies in breeding, experimentation, and commerce. However, natural outcrossing does offer the opportunity for recombination by open-pollination that could be used to advantage in recurrent selection and in hybrid cultivars. Genetic and breeding systems are needed that capitalize on the outbreeding tendency, yet avoid the problem of imposing isolation for production of selfed seed. The ICPL lines produced by ICRISAT using controlled selfing within standard cultivars are clear evidence of the potential advantages that would result if it were possible to treat pigeonpea as a naturally self-pollinated crop.

Two systems that enforce or predispose strongly towards self-pollination have been identified. Reddy (1979) described a "cleistogamy" character involving anthesis in the young bud. However, it was derived from an intergeneric cross and involves gross floral abnormalities; therefore it requires detailed study before use. In Australia, we have identified a modification of floral morphology involving overlapping lobes of the standard petal. In our conditions, the "wrapped" flower enforces self-pollination even in the presence of honeybees *(Apis melifera);* for example, cv Royes has wrapped flowers and invariably exhibits less than 2% off-type progeny, and male sterile plants with wrapped flowers produce few pods under open-pollination. The mechanism of action is not known but is probably mechanical. Honey and native bees work wrapped flowers but presumably are unable to do so sufficiently early in floral development to cause significant outcrossing. Other insect vectors not present at these sites may work such flowers prior to anthesis but in the absence of evidence of this, we conclude that the wrapped flower ensures virtually complete self-pollination.

The wrapped flower character occurs relatively commonly within the University of Queensland material, and in all cases has involved so-called vegetable types — large numbers of seeds per pod and large seed. The character is particularly common in West Indian accessions. We have sighted no reports of level of outcrossing in the West Indies. However, the uniformity of those accessions in Australia implies a high degree of self-pollination in the

West Indies, and Abrams (1975) reported an average of only 6% natural outcrossing in Puerto Rico. This is much lower than reported elsewhere (Khan, 1973, 40%; Green et al. 1979, 21%) and experienced under open-pollination of simple flowered lines in Australia. It seems probable that the wrapped character is genetically associated with large pods and seed, so that its variable frequency in pigeonpea populations internationally may be a correlated response to selection for particular seed sizes. Aspects of this character will be reported in a separate publication.

The wrapped flower character appears to be simply inherited and dominant, and can be recovered in all phenological groups. Thus it can be used to establish the logistically simple, classical breeding systems for selfed plants, directed towards pure-line cultivars that can be maintained without isolation. This would have massive impact on breeding methods, genetic maintenance, and commercialization.

Many potential parents (elite cultivars and genetic stocks) will have simple flowers. These could be used as parents in biparental crosses between elite wrapped and simple flowered lines, with truncation in the F_2 and subsequent generations to discard all simple-flowered segregates. Population improvement could be undertaken using open pollination of populations segregating for the wrapped and male sterile characters. One such scheme is outlined in Figure 2, which incorporates a composite cross backup population and recurrent selection based on F3 line progeny test. The population would be recycled using open-pollinated progeny of sterile segregants within elite progenies, and superior fertile lines homozygous for the wrapped trait would be selected for advanced testing. Numerous variations on this scheme are possible. One such population would be required for each phenological group of interest. Introgressions across phenological groups could be done using open pollination in short-day sowings to synchronize flowering.

This concept of treating pigeonpea as a naturally selfing plant is compatible with the exploitation of heterosis in hybrid cultivars. Variants of the recurrent selection scheme (Figure 2) will allow selection for specific combining ability with nominated simple flowered, male sterile parents. Alternatively, simple flowers and male sterility would be backcrossed into wrapped, fertile parents with superior combining ability, and the stock used in the normal manner to produce single-cross hybrid seed. The simple-flowered female parent would be heterozygous for sterility and would need to be maintained in isolation if other methods are unavailable.

It is emphasized that considerable study of the wrapped flower character is necessary to confirm its effects, usefulness, and character associations. However, it is one potential method of modifying the mating system of pigeonpea to allow the use of simpler and more rigorous breeding methods and efficient pure seed production. Considerable advantages result from the treatment of pigeonpea as a self-pollinating plant.

Introgression Across Production Systems

The wide diversity of phenological groups and production systems in pigeonpea creates particular problems forthe local breeder in gaining access to specific characters of interest in relevant genetic backgrounds. Local conversion of genetic stocks or transfer of the characters of interest to the required background would involve substantial duplication of effort. Introgression is expensive and requires continuity of genetic input, and can be conducted more efficiently at a central institute as a service *to* all production systems. This has already been initiated by ICRISAT, e.g., in transfer of disease resistance and male sterility, in selection of insect resistance and in distribution of segregating populations in a range of genetic backgrounds.

Such activity is fostered by the excellent program of scientific exchange established by ICRISAT, which provides personal contact, inspection of genetic material, and opportunity for feedback. Centralized plant improvement should be supported and fostered, and all breeders should exploit the resources of the central program to the fullest extent possible. The proposed "Pigeonpea Newsletter" will enable rapid dissemination of information on new problems or findings, and should result in accelerated plant improvement.

The problems involved in establishing introgression as a central service to all production systems should not be underestimated. These

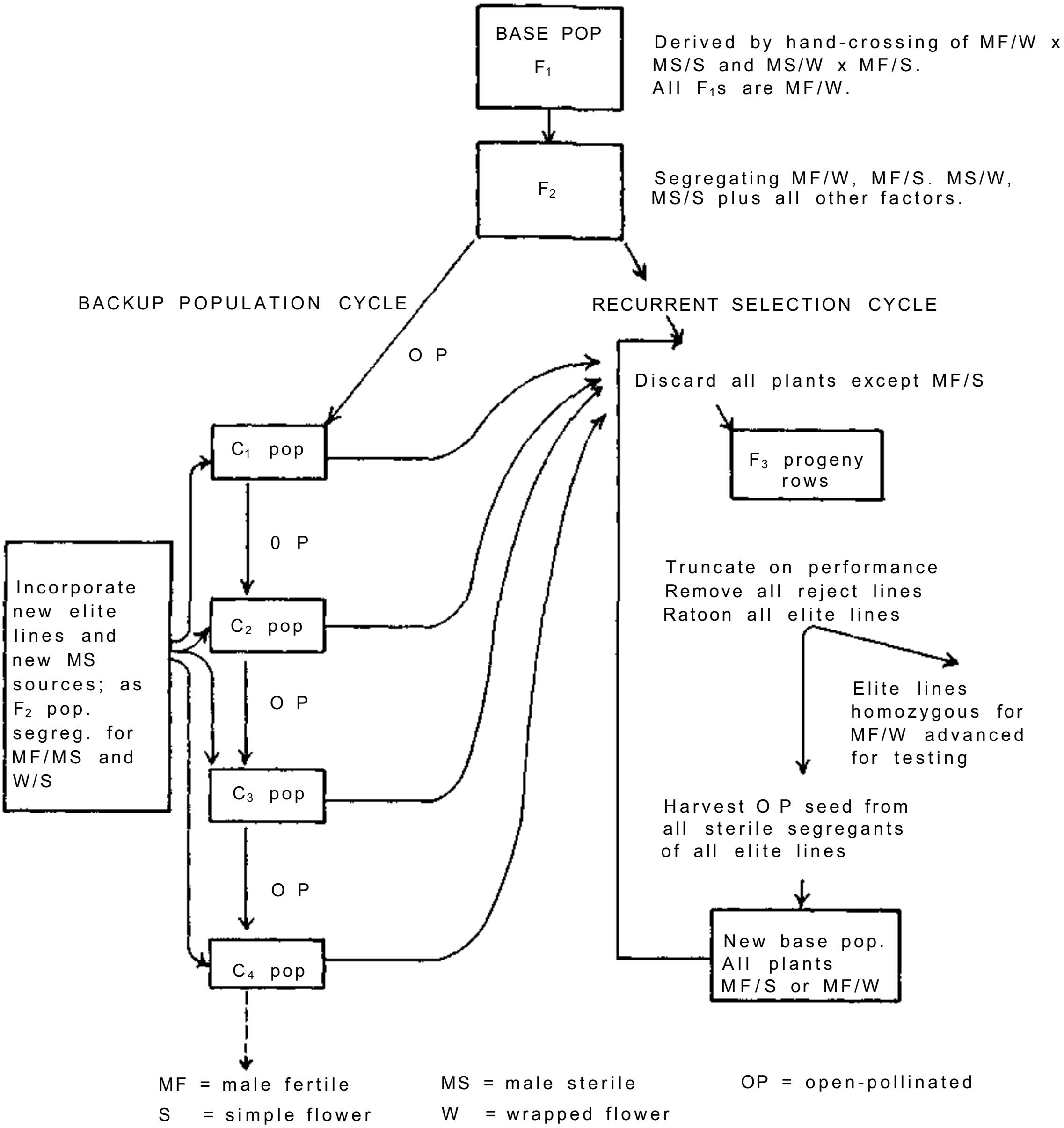

Figure 2. A scheme for population improvement and recurrent selection in pigeonpea utilizing open pollination, the wrapped and simple flower forms and genetic male sterility. Such a scheme would be required for each production system of relevance.

include the identification of need, the development of an appropriate breeding system, and decision on the stage of breeding at which genetic material is made available to the various national and local programs. In Australia, we have attempted introgression across phonological groups, using an open-pollinated polycross within a caged area incorporating bees. Off-season sowings and ratooning are used to synchronize flowering. This method is cheap and convenient and deserves further study.

In view of the low heritability of many agronomic traits on a single-plant basis, and the importance of genotype x environment interaction, we consider that initial local evaluation should involve relatively unselected progeny tests rather than bulk populations. This approach requires greater resources in the central program but should result in more effective conduct of local programs.

Pest and Disease Resistance

Crop losses due to insect pest and disease attack are substantial in pigeonpea. Considerable advances have been made at ICRISAT in genetic resistance and are major contributions to international pigeonpea improvement. Centralized research in these areas should be fostered.

Insect Pest Resistance

Three basic approaches to genetic improvement in pest resistance exist: crop scheduling to reduce or avoid the economic damage, identification and incorporation of host plant resistance, and development of tolerance. Nongenetic control is also possible, and integrated pest management, utilizing all systems, is optimal.

In practice, the usefulnessof these methods of control will vary in the different cropping systems. The prospect for nongenetic control via chemical or other agents is remote in the traditional long-season systems, and genetic protection via crop scheduling and host plant resistance/tolerance should be emphasized. In contrast, the full suite of pest management systems is likely to be required in full and short-season crops. The greater yield potential and the need for precise crop scheduling for ratoon crops and rotations justify the increased inputs.

It is important to note that the identification and incorporation of effective and durable host plant resistance in agronomically desirable cultivars could have basic influence on the relevance of the production system per se. The availability of such material would lead to fundamental change in management of the crop in order to optimize yield per unit area or per day rather than to reduce the probability of insect damage. In general, such changes would be away from long-season culture towards full- and short-season production systems.

Physiological studies involving defoliation and removal of reproductive structures (Sheldrake et al. 1979) have demonstrated that pigeonpea has a high physiological threshold of damage, largely related to temporal adjustments. This implies high tolerance to insect attack. However, this research needs to be extended to other phenological groups and production systems. There is no reason to believe that the mechanisms of tolerance in long-season plants at low density operate in short-season plants grown at high density. Indeed, temporal compensation may be unacceptable in such systems.

The extent and nature of integration of breeding for pest resistance/tolerance/avoidance with the general quantitative breed ing of the crop is debatable. We consider that breeding for insect pest resistance should be conducted separately from, but complementary to, the main quantitative programs. Classification for insect resistance is complex, expensive, and uncertain, and the heritability of resistance is therefore low. It *would be counterproductive to risk the* effectiveness of quantitative selection to obtain information of unknown reliability on insect resistance. The primary objectives of the programs are different and complementary, and should not be confounded. Thus, while breeding for pest resistance may involve controlled or augmented pest populations, the quantitative program should be protected from significant insect attack that can bias selection in the early generations. It should, however, incorporate parentage known to possess pest resistance, and include final testing of elite lines for pest resistance.

Disease Control

Genetic resistance is the only practical protection from the major diseases of pigeonpea, and much progress has been made in developing it. In general, the arguments presented on breeding for insect resistance also apply to disease resistance. Two additional aspects deserve mention. First, although different diseases and/or physiological races may exist regionally, the problem can be handled efficiently by a central research program with containment facilities, supplemented by facilities for regional testing. Second, while major gene protection has been viable to date, more generalized systems of resistance may be necessary if breakdown occurs. This could present significant challenges in breeding, and considerable fundamental research would be necessary before such breeding could commence.

Accelerated Generation Turnover

The length of most breeding programs adversely influences their cost and effectiveness. Techniques that accelerate generation turnover can reduce or avoid bias in selection in early generations, allow more rapid development and testing of fixed lines, and make programs more responsive to contemporary demand. However, such techniques generally involve some form of compromise.

Accomplishment of accelerated generation turnover (AGT) in pigeonpea is hindered by the wide range of phenology of interest, the relatively poor understanding of the control of floral induction and development, and the large size of the plant. A two-generation-per-year system is possible in the field in India for material up to ST-1 type maturity (110-120 days to flowering for sowing at the longest day), using particular sites for generation turnover. This has many applications in breeding.

AGT in the field does not appear feasible for later material or for segregating material from late x early crosses. Facilities providing short days and temperature control may be necessary to accomplish AGT for the entire range of phenology in pigeonpea. Harvesting of seed prior to normal pod maturity can also be used to shorten the crop cycle.

Significant benefits will flow from the accomplishment of AGT. Within pedigree breeding schemes, it would allow implementation of single-seed-descent schemes, earlier progeny tests of fixed lines, and greater flexibility of exchange of advanced breeding material. Recurrent selection schemes can be conceived involving recombination by open pollination within an AGT program. The attainment of control of phenology and AGT has important implications for pigeonpea improvement in general, and is particularly important in introgression across the phenological groups.

Use of Hybrid Cuitivars

Research by ICRISAT into varietal hybrids of pigeonpea based on genetic male sterility (Reddy et al. 1977) has demonstrated considerable heterosis for seed yield (Green et al. 1979). While there are prospects for widespread use of hybrid cuitivars in India, the research has been restricted to one form of male sterility (translucent anther) and one phenological group, and there is urgent need to broaden its base.

The results for hybrids based on MS3A and MS4A suggest that heterosis is largely a function of increased biomass. While this is an effective mechanism for long- and full-season cropping at low plant populations and for intercropping, its relevance in short-season, high-density systems is doubtful. Clear evidence exists that increased plant population will compensate in seed yield for inadequate biomass, and this is a much simpler technical innovation.

There have been no reports of the effects of plant density, level of management and production, or of phenology different from MS3A/4A on the extent and mechanism of heterosis. Transfer of male sterility from MS3A/4A to other maturity groups is in progress at ICRISAT (Reddy 1979) and in Australia (Saxena et al. 1980). In Australia, a different source of male sterility has been recovered in a large podded, large white seeded background, ranging from 50 days (photoperiod insensitive) to 80 days to flowering for sowing at the longest day (Wallis et al. 1981b). As a result, hybrids of different phenology can be produced. Their evaluation at optimal density in a range of production systems will help clarify the utility of hybrid cuitivars.

In practice, the economics of hybrid seed production is prejudiced by the need for manual rogueing of fertile plants from the population to be used as the female parent. This problem would be reduced by conducting hybrid seed production in optimal conditions for yield, efficient use of ratooning in crossing blocks, and by the identification of a simple marker gene linked to male sterility. Pure-breeding male-sterile populations would revolutionize hybrid seed production in all countries. This may eventually be possible using cytoplasmic maie sterility (Reddy 1979). For genetic male sterility, research is required into tissue culture for clonal propagation of sterile lines, and into chemical induction of seed production by male sterile plants.

Ratooning Ability

Unlike most field crops, the pigeonpea is a short-lived perennial and this confers attributes that may be exploited in its improvement. The primary advantage is in the capability for ratoon cropping in favorable environments. This is used commonly in breeding for seed increase and hybridization (Saxena et al. 1976). Although ratooning is not an integral part of any traditional production system, it offers real potential benefits, both in enabling additional harvests without the cost and delay of establishing another crop and in conferring flexibility of management in land use.

One or more ratoon crops are possible and high seed yield have been reported in favorable environments (Wallis et al. 1979b). Ratooning can be used to exploit residual moisture (Sharma et al. 1978). Crops ratooned under inductive conditions flower rapidly, but careful crop scheduling of photo-sensitivegenotypes is necessary to ensure this occurs (Wallis et al. 1979a).

Ratooning ability is a distinct genetic character. While it is compatible with the attainment of high seed yield in the plant crop (Wallis et al. 1979a), seed yield of the ratoon is influenced strongly by plant survival. Thus research is required to determine optimum agronomic practices for plant and ratoon crop performance, and the extent of gentic differences in ratooning ability and ratoon yield. Disease-resistant genotypes would assist in the maintenance of plant stand.

Multienvironment Testing and Genotype x Environment Interaction

The common field evaluation trial is the centerpiece of agricultural research. It is the primary point of contact between scientific contributions to plant improvement and the diversity of the production environment. Performance in such trials reflects adaptation reactions, and genetic/physiological and environmental limitations, which have implications in two directions — forward into production practice, cultivar release, and recommendation, and backwards into the objectives and strategies of plant improvement per se.

Despite this pivotal role, resources for such trials are rarely adequate to ensure effective conduct and rigorous analyses of the results. Further, it is unfortunately true thatthe trials are normally conducted by breeders and agronomists and the results are largely ignored by other disciplines. As a result, the attention of the entire plant improvement team is not focused on real limitations to production and possible solutions.

To date, effective coordinated multienvironment testing has not developed in pigeonpea. There are many reasons for this; for example, gross heterogeneity of breeding lines and check cultivars, lack of standardization on optimal agronomic recommendations for different production systems, high incidence of missing data dueto inadequateplant stand, limited reporting of associated plant and environmental data, and inadequate plot technique that leads to high errors. Presumably, this reflects lack of appreciation of the importance of such trials in production and in guiding plant improvement of this crop. The fact that effective programs do exist in other crops is particularly disturbing.

Two forms of benefit arise from effective multienvironment testing programs. First, individual programs gain access to the best breeding lines available and to reliable information on their local performance. This directly influences release and recommendation of cultivars. Second, all programs benefit from detailed combined analysis of the trials, in terms of improved understanding of the adaptation of the entries, identification of environments that impose particular limitations to performance, and more effective definition of objectives in plant improvement.

In the absence of reliable data on pigeonpea, analogies must be drawn from other crops to demonstrate the usefulness of combined analysis of adaptation. A conceptual basis for such analyses was discussed by Byth (1977) and will be considered only briefly here. Genotype x environment interactions are commonly complex and multivariate in nature, and require careful analysis. While various statistical procedures, such as joint linear regression on an index of the environment, have been useful in conceptualizing adaptation, they have proved to be of limited value in most field crops because the form of response is generally nonlinear (Eisemann et al. 1977). Conversely, multivariate analysis (particularly pattern analysis) has proved to be powerful in characterizing adaptation in a wide range of crops. For example, in ISWYN 4 wheat data from CIMMYT, cluster analysis of the entries and of the environment was used to reduce the original 49 entry x 63 environment matrix to a 10 x 10 matrix of group means. The group composition reflected, in part, the origin and parentage of the entries. Data reduction facilitated recognition of marked differences in environmental response of the groups of entries (Figure 3) (Byth et al. 1976). Additional information can be obtained on the cause of such differences in adaptation, and on the usefulness of particular environments in discriminating among the entries (Shorter et al. 1977; Brennan et al. 1980).

An understanding of the adaptation of pigeonpea can be derived from such analyses of data from an effective coordinated trial series. Establishment of such a series is of basic and immediate importance to the continued improvement of this crop.

Broadening of the Genetic Base

Utilization of Germplasm

Despite considerable breeding efforts in India and elsewhere, most commercial pigeonpea production is based on landraces. There is little evidence of narrowness of the genetic base of this crop. A large germplasm collection has been assembled, and aspects of it have been described in other papers at this workshop.

Full exploitation of the germplasm in improvement is particularly important in pigeonpea because of its diversity of habit and use. Assessment of genetic value of accessions is relatively simple for qualitative characters such as disease resistance, but is more complex for quantitative characters. Phenotypic characterization requires multi-environment evaluation and is probably feasible only as a long-term phased program. Genetic evaluation requires a progeny test, and poses additional problems regarding the appropriate level of introgression of exotic germplasm.

While characterization of germplasm is necessary, additional opportunitiesfor its use in long-term improvement may result from development of "backup" composite cross populations. Logically, these would be based on phenological class and be cycled by open pollination within particular production systems.

Intergeneric Hybridization

Pigeonpea belongs to a monotypic genus, and it is logical to seek additional variability in related genera. Many collections of species of *Atylosia* and other genera have been made, generally from nonagricultural situations *over a* wide ecogeographical range. Intergeneric hybridization has been successful in some cases and other crosses may be possible using bridging species.

Some potentially useful characters have been identified in *Cajanus* x *Atylosia* derivatives, including cytoplasmic male sterility and partial resistance to *Heliothis* (Reddy 1979). It is also possible that wild relatives possess other physiological mechanisms of adaptation not present or poorly developed in *Cajanus,* such as adaptation to high pH soils, moisture stress, heat or frost tolerance, etc. Detailed physiological analysis of the wild species per se is justified on this basis alone, since such characters could considerably broaden the adaptation of pigeonpea. Similarly, genetic study of intergeneric hybrids and of introgression of the related species needs to be strengthened.

Such research should be conducted at a central research institute, or supported by it elsewhere.

Other Methods

Adequate genetic variability exists for most characters in pigeonpea. In general, there is little justification for the use of sophisticated procedures for generation of variability until existing sources are exploited in breeding. Nevertheless, alternative approaches to breeding exist, and their application needs to be considered.

Mutation breeding using chemical and physical mutagenic agents has been little studied in pigeonpea. It is likely to have greatest application for qualitative characters in which appropriate genetic variability is limited or absent, e.g., disease resistance. However, in the absence of elite, genetically pure cultivars, its use in quantitative breeding is difficult to justify.

Recent developments in cell and tissue culture (Murashige 1974) could have application in pigeonpea breeding. These include selection in in vitro cell culture for particular mutants (Chaleff and Carlson 1974), anther and pollen

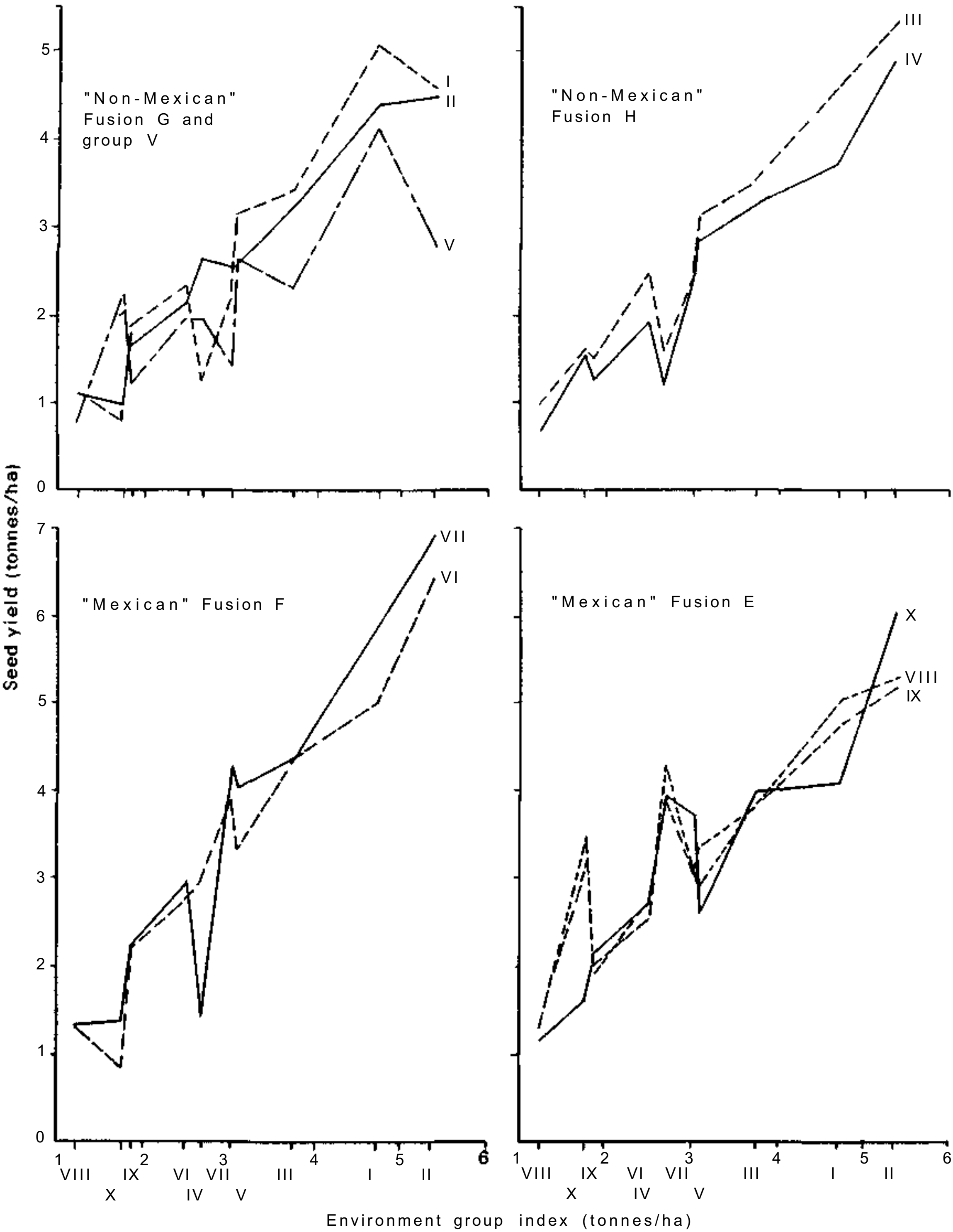

Figure 3. Yield performance of cultivar groups across an environmental group index. Groups formed by two-way cluster analysis of ISWYN4 deta, CIMMYT (Source: Byth et al. 1976).

culture to produce doubled haploid plants (Guha and Maheshwari 1964), protoplast fusion (Power et al. 1970), parasexual hybridization (Carlson et al. 1972) and transformation and transduction (Bottino 1975). At this stage, research is needed to develop the technology of cell and tissue culture in pigeonpea, but we see little justification for a large investment of resources in this work.

International Collaboration and Exchange of Breeding Material

The primary factor in the long-term improvement of pigeonpea internationally is the ICRISAT charter program. While individual initiative in national and local programscan result in major advances, capitalization on that advance and its incorporation into other material and production systems can be facilitated using ICRISAT resources. Commonsensedictates that local programs make maximum use of the genetic and scientific resources at ICRISAT, including participation in the training programs. ICRISAT is responsible for establishing effective international collaboration and forfostering development of the national programs.

The potential benefits of collaboration in plant improvement are tangible and self-evident, and relate to three basic items: rapid exchange of new concepts and discoveries, improved access to genetic material, and opportunity for scientific exchange among and within disciplines. The proposed "Pigeonpea Newsletter" will be a useful service in communication, as are the excellent scientific exchanges and meetings fostered by ICRISAT.

While genetic exchange is central to plant improvement, it can be of limited value or even a positive hindrance to local programs if it is inappropriate to their needs; e.g., supply of excessive or nonadapted material, or of populations at a stage of selection not relevant to local facilities. Considerable attention needs to be given to the forms of collaboration appropriate to each situation in order to foster constructive exchange and to support the local programs. Adoption of plant improvement stratified on phenology and production system will facilitate this.

Synopsis

Certain key items need to be considered in international pigeonpea improvement:

1. Strengthening of interdisciplinary collaboration in plant improvement.
2. Identification of production systems relevant to a region and definition of breeding objectives specific to them. Integrated agronomic study of the system is required.
3. Definition of the role and objectives of the central improvement program and of international collaboration, and strengthening of their activity.
4. Modification of the mating system to simplify breeding and pure seed production, and development of breeding procedures to exploit the advantages of the mating system. This includes accelerated generation turnover.
5. Strong emphasis on host plant resistance/tolerance/avoidance of pest and disease attack, and on integrated pest management.
6. Use of cultural inputs as breeding tools to enable more effective discrimination, and testing of their relevance in production systems.
7. Research into hybrid cultivars, their relevance and feasibility in different systems.
8. Utilization of the advantages of perenniality in breeding and production.
9. Broadening the genetic base, particularly with respect to potentially innovative characters that may influence adaptation.

In this paper, we have concentrated on crop adaptation and general strategies of plant improvement, and deliberately have not considered quantitative genetic analyses, specific breeding methodology and objectives, or breeding for nutritional quality. While quantitative genetic analysis is important, meaningful estimates can be obtained only within populations exhibiting the same general adaptation. Inclusion of parents with contrasting adaptation (say for phenology) in mating designs inevitably results in confounding the genetic estimates with pleiotropic effects due to the influence of physiological differences. Thus we believe that clarification of crop adaptation must precede quantitative analysis. Similarly, breeding methodology and objectives can only be defined sensibly in relation to the requirements of specific systems. While nutritional quality is important, the improvement of crop adaptation, yield, and protection must be considered the serious challenge in pigeon pea improvement at this stage.

References

ABRAMS, R. 1975. Status of research on pigeonpeas in Puerto Rico. Pages 141-147 *in* Proceedings, International Workshop on Grain Legumes. ICRISAT, 13-16 Jan. 1975, Hyderabad, India.

BOTTINO, P. J. 1975. The potential of genetic man ipulatbn in plant cell cultures for plant breeding. Radiation Botany 15: 1-16.

BRENNAN, P. S., BYTH, D. E., DRAKE, D. W., DE LACY, I. H., and BUTLER, D. G. 1980. Determination of the location and number of test environments for a wheat cultivar evaluation program. Australian Journal of Agricultural Research (In press).

BYTH, D. E., EISEMANN, R. L, and DE LACY, I. H. 1976. Two-way-pattern analysis of a large data set to evaluate genotypic adaptation. Heredity 37: 215—230.

BYTH, D. E. 1977. A conceptual basis of G x E interactions for plant improvement. *In* Proceedings, Third International SABRAO Congress. Feb 1977, Canberra, Australia, 3(d): 1.

CARLSON, P. S., SMITH, H. H., and DEARING, R. D. 1972. Parasexual interspecific plant hybridization. Proceedings, National Academy of Science, USA 69: 2292-2294.

CHALAFF, R. S.,and CARLSON, P. S. 1974. Stomatic cell genetics of higher plants. Annual Review of Genetics 8: 267-278.

EISEMANN, R. L , BYTH,D. E., DE LACY, I. H., andTAYLOR, P. J. 1977. A comparison of some methods of analysis of GxE interactions and adaptation responses in a large data set. *In* Proceedings, Third International SABRAO Congress Feb 1977, Canberra, Australia 3(d): 41.

GREEN, J. M., SHARMA, D., SAXENA, K. B., REDOY, L. J., and GUPTA, S. C. 1979. Pigeonpea breeding at ICRISAT. Presented at the Regional Workshop on Tropical Grain Legumes. University of the West Indies, 18-22 June 1979, St. Augustine, Trinidad.

GUHA, S., and MAHESHWARI, S. C. 1964. *In vitro* production of embryos from anthers of *Datura.* Nature 204: 497.

KHAN, T. N. 1973. A new approach to the breeding of pigeonpea (*Cajanus cajan* Millsp.). Formation of composites. *Euphytica* 22: 273-277.

LAWN, R. J., BYTH, D. E, and MUNGOMERY, V. E. 1977. Response of soybeans to planting date in South-eastern Queensland. III. Agronomic and physiological response of cultivars to planting arrangements. Australian Journal of Agricultural Research 28: 63-79.

MURASHIGE.T. 1974. Plant propagation through tissue cultures. Annual Review of Plant Physiology 25: 135-166.

PATHAK, G. N. (1970). Red gram, pp 14-53 *in* Pulse crops of India (ed P. Kachroo). New Delhi, India: Indian Council of Agricultural Research.

POWER, J. B„ CUMMINS, S. E., and COCKING, E. C. 1970. Fusion of isolated plant protoplasts. Nature 225: 1016-1018.

REDDY, B. V. S., REDDY, L. J., and MURTHI, A. N. 1977. Reproductive variants in *Cajanus cajan* (L.) Millsp. Tropical Grain Legume Bulletin 6: 11.

REDDY, L. J. 1979. In Pigeonpea breeding. ICRISAT Pulse Breeding progress report 3, Patancheru, A. P., India.

SAXENA, K. B., SHARMA, D., and GREEN, J. M. 1976. Pigeonpea ratooning — an aid to breeders. Tropical Grain Legume Bulletin 4: 21.

SAXENA, K. B., WALLIS, E. S., and BYTH, D. E. 1980. Development of a photo-insensitive male sterile line of pigeonpea (*Cajanus cajan* [L.] Millsp.). Available from the author.

SHARMA, D., SAXENA, K. B., and GREEN, J. M. 1978. Potential of ratooning in pigeonpea. Field Crops Research 1: 165-172.

SHELDRAKE, A. R., NARAYANAN, A., and VENKATARATNAM, N. 1979. The effects of flower removal on the seed yield of pigeonpeas *(Cajanus cajan).* Annals of Applied Ecology 91: 383-390.

SHORTER, R., BYTH, D. E., and MUNGOMERY, V. E. 1977. Genotype x environment interactions and environmental adaptation. II. Assessment of environmental contributions. Australian Journal of Agricultural Research 28: 223-235.

SPENCE, J. A., and WILLIAMS, S. J. A. 1972. Use of photoperiod response to change plant design. Crop Science 12(1): 121-122.

TURNBULL, L.V., WHITEMAN, P.C., and BYTH, D. E. 1981. The influence of temperature and photoperiod on floral development of early flowering pigeonpea. Volume 2, these Proceedings.

WALLIS, E. S., WHITEMAN, P. C, and BYTH, D. E. 1979a. Pigeonpea — a new crop for Queensland. Queensland Agricultural Journal 105(6): 487-492.

WALLIS, E. S., WHITEMAN, P. C, and BYTH, D. E. 1979b. Pigeonpea (*Cajanus cajan* [L.] Millsp.) production systems in Australia. Presented at the Regional Workshop on Tropical Grain Legu mes. University of the West Indies. 18-22 June 1979, St. Augustine, Trinidad.

WALLIS, E. S., SAXENA, K. B., and BYTH, D. E. 1981a. Flowering responses of thirty-seven early maturing lines of pigeonpea. Volume 2, these Proceedings.

WALLIS, E. S., SAXENA, K. B., and BYTH, D. E. 1981b. A new source of genetic male sterility in pigeonpea. Volume 2, these Proceedings.

Discussion — Session 10

Williams:

Why do you bag 25 plants to maintain the germplasm? Could it be done with five, or three, or two plants?

Remanandan:

We do this to reconstitute the genetic variation of the original collection without losing the original characters, as far as possible. Twenty-five is a more or less arbitrary number, which we have fixed keeping in view the resources available and the need to capture the maximum number of characters.

Green:

Jack Harlan suggested using 30 plants to maintain variability in a sample.

Tiwari:

How does the ICRISAT Genetic Resources Unit screen for photo- and thermo-insensitivity?

Remanandan:

This is a venture we have undertaken in collaboration with the breeders on the basis of the few photoperiodic groups identified by ICRISAT breeders.

D. Sharma:

We planted material all year round. June-July, October-November, December, and February were found important. This information is documented in our annual reports. Screening for total insensitivity is done under 24-hour light.

Onim:

Should germplasm materials be maintained at more than one location to minimize genetic erosion? Maybe a second germplasm bank — in addition to the one at ICRISAT Center — should be established.

Remanandan:

ICRISAT germplasm is being maintained at more than one site.

Green:

There is great photoperiod x temperature response in pigeonpea. Another maintenance site is being considered, and Kenya is a likely site for the east and central African region.

Onim:

There should be multilocational testing of the germplasm also.

Wallis:

The data in Table 4 of the paper by Pankaja Reddy and N. G. P. Rao show yields of 2 to 8 kg per plot. But this is not reflected by data on seeds per plant.

N. G. P. Rao:

Replicated F_2s were grown and harvested for yield. The yield data are reported on whole plots, whereas on other characters data were recorded on a few plants only.

Green:

In your Table9, the effect of plant spacing is marked, with closer spacings giving higher yields. We have data indicating that 30-cm spacing in rows reduces yield. What was the soil type you used, and were the tests irrigated?

Pankaja Reddy:

The experiments were conducted on light black soils. We need to check records on the status of irrigation.

Avadhani:

I think that the yield of 15 plants in the F_2 is not representative of the yield of a cross, especially in a highly outcrossing crop like pigeonpea. In the F_2, every individual plant is different. I think the data are misleading.

Pankaja Reddy:

The F_2 yield trial comprised three replications, with each having approximately 150 plants per plot. However, individual plant observations were recorded on 15 random plants per plot. Plot yields are based on 150 plants.

Bhargava:

This is a comment to Dr. S. P. Singh on evaluation methods, If material generated by breeding is tested under different sets of nurseries with varying physiological conditions — for example, drought—it may be useful. The germplasm material should also be tested under moisture stress and possibly as an intercrop.

D. Sharma:

You have reported that very interesting material of 120 days' duration and four to five fairly large seeds per pod has been developed at IARI. I would like to know its background and pedigree.

S. P. Singh:

The pedigree of bold-seeded early-maturing material generated in our program is (8504 x ICPL-10) x Prabhat. Segregating progenies of this cross were received from ICRISAT. Crosses involving 8504 in other cross combinations are giving very encouraging results also.

Samolo:

From today's deliberations it is clear that somatic variation occurs in pigeonpea. Under such conditions, what will be the effect of this on the single-pod descent method? What is the percentage of somatic variation observed in pigeonpea and what is the source of it? Is it due to somatic crossing over, gene mutation, or chromosomal aberrations?

Green:

I believe the frequency of somatic mutation would be too low to disturb a population; however, fortuitous somatic mutations could be selected.

Nerkar:

Our work at Parbhani on the testing of early generation lines under sole and intercropping systems indicates that genotypic differences exist for response to the two systems. Selections made under intercropping in the early generation do show positive response to intercropping compared with sole cropping. Based on these observations, we proposed a two-tier selection procedure, with selection for yielding ability in the F_2 under sole cropping, followed by selection for yielding and companionship ability in subsequent generations under intercropping. Family performance rather than single-plant performance is preferred.

Much of the research presented here has indicated that a quantum jump can be made in pigeonpea production by the development of hybrids; however, this will take time. But we can certainly make a substantial advance in the meantime by resorting to composite breeding. In the method we are following at Parbhani, we (1) take selected parents with high GCA, mix crossed seeds, and grow them in isolation; (2) grow bulked F_2s and F_3s in isolation; (3) make a large number of elite selections in the F_4 and bulk these for testing.

Preliminary observations have indicated that there is yield improvement over the best check and also better performance under different cropping systems.

Green:

BDN-1 and 15-3-3 were selections from local germplasm and these can be put into composites.

Jagdish Kumar:

In his paper Dr. Nerkar suggested single-plant selection for yield in the F_2 generation. In view of the ineffectiveness of single-plant selection for yield, I wonder whether he would modify his approach.

Nerkar:

Yes. Selecting for family performance rather than single-plant performance would be better.

Joshi:

In spite of your 50% success in selecting in sole and intercrop situations, can the two not be combined? The question is, what kind of plant are you producing for sole cropping, and will it succeed under intercropping as well? Doyou use the Australian system of close planting with good top podding and a good canopy to increase number of pods per unit area and allow effective insect control? These types may not succeed under intercropping. Looking at this situation phenologically, if a particular genotype is tested under separated-row conditions and at the same time under close-packed conditions, what kind of response can we expect? What we are looking for is some sort of commonality in a given set of genotypes. Should we not look for some way of finding varieties with insensitivity to planting date and varying agronomic practices?

Byth:

The very point of photoinsensitivity is that it gives flexibility in sowing dates under a given agronomic system. Cultivar Royes, which is photosensitive, will give high yields under a wide range of planting dates, but agronomic practices must be varied according to time of year. Farmers do not want to do this. Thus we must find genotypes with less sensitivity to sowing date.

N. G. P. Rao:

Dr. Byth and his colleagues start with this basis: (a) photoperiod x temperature interactions affect phenology of genotypes, and (b) phenology is the basis for categorizing three production systems: Long-season, full-season, and short-season. Consequently, they suggest that improvement should be oriented towards these systems. They also suggest items for central and localized breeding programs.

My comment is that in all crop cultivars of traditional tropical subsistence systems, photoperiod-temperature responses were a rule rather than an exception. Success in making a system more productive was frequently achieved by going away from such responses rather than being limited by them. This should be recognized. Sorghum is one good example, in which almost the entire rainy-season sorghum area is treated as a single maturity zone.

Since pigeonpea is cultivated predominantly as a rainfed crop in the tropics, it is of greater consequence to tailor the duration of the crop-growing season and the total dry matter to the duration of the rainy season and the known fluctuations in moisture levels of various soil types. In so doing, if we capitalize on the wider germplasm resources to incorporate higher levels of productivity, the breeding programs will not only be meaningful but also have wider applicability.

I agree with Dr. Byth that breeding objectives should be oriented towards production systems, but I am afraid systems based on phenology may not furnish answers. The systems he suggests will tend to orient breeding more towards subsistence than towards dynamic, productive systems.

Some references to the breeding system in pigeonpea and breeding methodology reveal conflicting statements: (1) Isolation for seed production is not feasible. Why? (2) Heterosis is effective for full-season cropping at low densities but not for short-season, high-density cropping. Why? Our experience has been just the opposite.

Byth:

By basing production systems on phenology, we are not becoming its prisoners — we are creating a dynamic approach. Dr. Rao indicates that he wants to tailor the length of the crop to the length of the growing season. That is precisely what phenology does. So we agree.

The G x E interaction is a huge subject. The traditional system of partitioning variance on a biometrical basis has been found to be totally inadequate in terms of understanding the physiological basis of adaptation of a crop. For that reason, techniques like linear regression, cluster analysis, and others have become necessary and have proven their merit.

In India there is no isolation in the seed production systems, so we need a mechanism for isolation and several are available. Heterosis has only been analyzed in medium-season materials, and we need to find out more about the causes of heterosis and its extent in other phenological groups.

D. Sharma:

Phenology, as I understand it, is a process of development under specific environmental or agroclimatic conditions. Here it is being equated with the time or duration of flowering; thus there is not much difficulty in appreciating what the growing season is and what the requirements of the crop are at a specific location.

A lot has been said about systems of testing. Dr. Byth is right in emphasizing that we should be testing where the crop is to be planted. But the plant breeder wants to grow the crop where maximum variation is expressed. Several people suggest increasing precision in testing breeding material. Variation increases in favorable conditions but may decrease under adverse conditions. Selection should be done when variance is maximum.

Dr. Nerkar's data show very high CVs and therefore the conclusions about intercrop and pure-crop situations are difficult to accept. Our data suggest that grouping varieties within nonsignificant groups on the basis of ranking in the pure crop and intercrop gives a low level of reliability. There is much to understand in this system before we can reach any conclusions.

Tiwari:

What characteristics are likely to confer greater stability in grain legumes in general and pigeonpea in particular?

Byth:

Stability is a magic word in agricultural science, but no one knows what stability is. If it is uniform performance across environments and locations, then it is zero. Lowest yield will be the most stable. The inadequacy of the biometrical approach has resulted in this type of stability. Linear regression is useful to plant breeders, but we find that the vast majority of crops do not respond linearly, so we need multivariate analysis to study dynamic responses.

What physiological characters of plants influence performance in a given environment? I can answer this only in part: phenology is a big chunk of it. If we are able to understand why plants grow the way they do in a system, we can explain the differences.

Laxman Singh:

For higher environmental insensitivity in a particular production system, is it advisable to screen bulk populations in the F_2, F_3, etc., in instabilizing environments (under moisture stress, disease, pests)? Should we explore the advantages of heterogeneous populations in pigeonpea improvement?

Green:

I favor subjecting early generations to constant selection pressure such as disease screening, but prefer to delay selection for yield until advanced generations and then measure G x E interaction in muitilocation trials. More data are needed on the value of heterogeneous populations. Perhaps a pure line of the best plant in the population would give better performance.

Bhatnagar:

I have some comments on future strategies for pest resistance. In India, surveys in Andhra Pradesh and some districts of Maharashtra and Karnataka revealed two major pest-related factors that resulted in heavy yield losses in pigeonpea. First, local egg parasites do not parasitize the eggs of *Heliothis armigera.* Second, larval parasitism by hymenopterans was significantly lower than by dipterans on pigeonpea. These parasites locate their insect host, *Heliothis,* and flora preference utilizing factors different, presumably, from those used by *Heliothis.* Therefore, *Heliothis* has a wider host range than its parasites. During the course of this workshop, and particularly in this session, it has repeatedly been mentioned that it is difficult to breed pigeonpea resistant or tolerant to *Heliothis.* It is certainly complex, expensive, and uncertain.

I suggest that a multidisciplinary team determine and relate the complex role of physical and chemical factors involved in successful or unsuccessful parasitization in pigeonpea. This understanding may in future assist breeders to select *or* breed pigeonpea and other legumes with preference for indigenous egg parasites and hymenopteran larval parasites of *H. armigera.* Such a development in pigeonpea will give subsistence farmers realistic and sustained help.

In suggesting this new approach I am sure that I am not overestimating the potential of the pigeonpea genetic resources assembled in the 1970s. I suggest it not as a substitute for the earlier traditional approach but a complement to it, to hasten progress in breeding towards pest resistance.

Misra:

Since pigeonpea in the Indian subcontinent and some other countries is grown as a low-input crop, breeders should put segregating populations under selection pressure adopting low monetary inputs. Using this approach, desirable genotypes can be evolved simulating the conditions now prevailing in farmers' fields.

Green:

I agree that cultivars adapted to low-input systems should be improved. The traditional production systems (low-input) will be important for a long time to come.

Session 11
Critique and Synthesis

Chairman: J. S. Kanwar

Rapporteur: Y. L. Nene

Production

M. C. Saxena*

As a crop predominantly grown in tropical areas, pigeonpea is widely cultivated in semi-arid areas of india and Kenya and in subhumid regions of Uganda, the West Indies, Burma, and the Caribbean region. It is also becoming increasingly important in Central and South America, and attempts are being made to introduce it on a large scale in Australian agriculture.

About 90% of the world production, however, is contributed by India, and production changes in this region could have a corresponding effect on the world production. The per capita availability of pigeonpea has shown a decreasing trend in the last several years, with an obvious adverse effect on the nutritional situation in those parts of the developing world where pigeonpea is an integral part of the daily diet. Increasing the productivity of the conventional pigeonpea-based cropping systems as well as introducing its production into nonconventional areas, which received due emphasis in the keynote address as well, deserve the highest priority. Development of the components of improved crop-management practices, based on clear and sound understanding of the environmental adaptation of the crop on the one hand and the needs of different farming systems — including socioeconomic considerations — on the other, is of vital importance.

The deliberations of the present workshop have helped to identify such components and to highlight the areas that should be assigned high research priority. Under the broad heading of production there were five presentations in the first session, dealing with thetraditional as well as nontraditional cropping systems, covering a wide range of agroecological conditions. One paper in the session on pathology focused attention on weed management. Ten more presentations in other sessions covered various aspects of the environmental adaptation of the crop; its nutrition, including symbiotic nitrogen fixation; water relations; gas exchange; and radiation interception by the crop canopy. All these papers, as well as the nine volunteer papers, served well to complement the presentations on cropping systems. In general, the coverage of review papers was good and up-to-date.

The contribution on climatic environment for pigeonpeas examined the elements of climate for principal pigeonpea-growing areas in India and, based upon these, suggested the isoclimes of areas in West Africa where introduction of pigeonpea could be successful. It was pointed out that in agricultural subdivision I (semi-arid northern alluvial zone) and II (semi-arid central upland zone) of the pigeonpea-growing regions in India, the moisture availability indices were good, whereas in subdivision III (semi-arid lava plateau zone with undependable rains) they were poor. The need for adoption of crop-management practices to avoid water logging in the northern and central region and to conserve moisture in the southern region of India was highlighted. By implication, it appears that the lower productivity of pigeonpea in the southern region may be attributed to higher thermal regimes and lower moisture availability indices. More detailed evaluation of the climatological data is needed to conclusively establish a relationship. This would also help in the identification of new niches for pigeonpea in the cropping systems of some of the areas where pigeonpeas are not traditionally grown.

Although the conventional cropping system is dominated by intercropped pigeonpea, sole-crop pigeonpea is also grown and it seems to offer more scope for nontraditional areas and cropping seasons. As a sole crop, pigeonpea was shown to be relatively inefficient in intercepting the incoming solar radiation, because of its slow rate of initial growth. In one of the presentations, it was shown that the yield of pigeonpea was inversely related to the time taken to attain a leaf area index of 1. By selecting fast-growing, early-maturing genotypes and by appropriate manipulation of plant population, it was possible to increase the light interception, as was clearly demonstrated by the work presented from Trinidad and Australia, and as also

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established earlier in the work of All India Coordinated Pulse Improvement Project. Genotypes that can retain better pod set in thicker stands so that a higher harvest index is realized would be ideal for such cropping systems. Evidence for the existence of genotypic differences in this regard was presented in one of the papers.

Sole-crop pigeonpea has been found suitable for multiple cropping using extra-early cultivars, which have now become available; however, efforts to identify still higher yielding, photoinsensitive varieties with high harvest index should be continued. Multiple-cropping systems involving an extra-early-maturing sole crop of pigeonpea must be evaluated in comparison with alternative cropping systems in terms of economic superiority and practical feasibility.

Introduction of a crop or genotype into a multiple-cropping system necessitates the matching up of the crop or genotype with the major elements of the environment. Ability to predict the phenology of a genotype through studies under controlled environment is of importance in this regard, and efforts already initiated in this direction must be continued. How such an understanding can be of help in developing new cropping systems was well exemplified by a presentation on mechanized dry seed production of pigeonpeas in Queensland, Australia.

Sole crops of extra-early varieties of pigeonpea could be introduced in rotation with wheat in such nontraditional areas where traditional long-duration varieties of pigeonpeas cannot be grown. Data were presented to suggest that there is good scope for such introduction in those parts of the Punjab, Haryana, Himachal Pradesh, Rajasthan, and Madhya Pradesh that have recently come under irrigation. Advancing the date of planting of these early-maturing pigeonpea genotypes to April, which is possible under assured irrigation, appears to confer decided advantages resulting not only in higher grain yield but also in higher total phytomass, a substantial portion of which would be useful as firewood.

Studies on fertilizer response of such early-planted crops have shown that the pigeonpea crop is responsive to phosphate application. The need for developing appropriate manurial schedules in terms of rates and phasing of application in relation to soil nutrient status and cropping sequence is obvious. Studies on water management of sole-crop pigeonpea have revealed that the crop could be benefited when stresses during the reproductive growth period are relieved by irrigation. The possibility of identifying genotypes that would respond better to improved moisture supply should be examined.

The scope for postrainy-season, or rabi, pigeonpea cropping also appeared very promising in various agroecological conditions in northeastern, central, and southern India. Lands vacated by rainy-season maize, early paddy, minor millets, and jute for fiber; flood-prone areas of Bihar and eastern Uttar Pradesh after the receding of floodwater; the drier uplands in the Murshidabad district of West Bengal; the coastal region of Orissa; the Raipur and Bilaspur districts of Madhya Pradesh; rice-growing areas of Karnataka and Tamil Nadu; and heavy blackcottonsoilsand coastal areas of Andhra Pradesh offer promise for the introduction of rabi pigeonpea.

Appropriate agronomic management practices for this system have to be developed, however, for different regions. Studies in Andhra Pradesh, for example, showed that performance of rabi pigeonpea could be substantially improved by *Rhizobium* inoculation in conjunction with phosphate application. Studies in Bihar showed that the date of planting of the rabi crop is critical, and, as would be expected, the crop being sown in inductive photoperiods responded well to increased plant population by compensating for reduced vegetative growth. The new system may however carry a greater risk of new disease and pest complexes for which careful watch will have to be kept.

Because of the slow rate of leaf area development in the early stages of crop growth, the light interception and dry-matter accumulation in a sole crop of pigeonpea are less than in several other crops grown in the same season. The interception of incident solar radiation and exploitation of other environmental resources can be improved by adopting intercropping of pigeonpeas with compatible but fast-growing companion crops of cereals or legumes. Farmers have followed for ages intercropping and mixed-cropping systems for pigeonpea in major pigeonpea-growing areas all over the world. Recent researches, which have been well reviewed in the presentations, have led to the development of intercropping systems that are more productive and can stabilize the yields at a level higher than those usually obtained by the farmers in the semi-arid tropics. Using very fast-growing genotypes of mung beans, urd beans, compact cowpeas, early groundnuts, etc., in a parallel-cropping system, it has been possible to have intercropping even in early-maturing varieties such as T-21, resulting in almost as much yield of intercropped pigeonpea as is obtained from a sole crop, plus an additional yield from the intercrop.

In the medium-duration and late varieties, intercropping systems of great promise have been identified. At ICRISAT, it has been possible to get almost a full yield of sorghum plus 72% of pigeonpea yields in the pigeonpea/sorghum intercropping experiments on Vertisols. Such a system seems to have an edge, economically speaking, over a double-cropping system. Even on Alfisols, where double cropping is not possible, 40 to 50% of the sole-crop yield of pigeonpea could be obtained when pigeonpea was intercropped with sorghum, clearly establishing the superiority of this system over sole-crop sorghum. Similarly, a pigeonpea/groundnut intercropping system gave average yields equivalent to 82% of sole groundnut plus 85% of sole pigeonpea.

Intercropping systems such as these havethe advantage in terms of improved moisture-use efficiency, fertilizer-use efficiency, and weed control. But considerable further research is needed for making these systems more stable and productive. Studies have shown that there is little correlation between the performance of a genotype of the component species in the intercropped system and that in the sole-crop system. Therefore genotypic evaluation will have to be done specifically following this planting system. Studies are also needed for developing appropriate planting geometry and spatial distribution of the main crop and intercrop and for establishing appropriate plant populations of the components per unit area so that productivity with respect to these variables may be optimized. Studies on the moisture use of the component crops, of the type reported for the sorghum/pigeonpea intercropping system from ICRISAT, are needed for other systems and agroecological conditions. Better understanding is needed of the nutrient removal pattern of the intercrop system from different parts of the soil profile and the interaction of the component crops for nutrient uptake. Identification of genotypic differences in this could make it possible to develop more efficient intercropping combinations. Fertilizer rate and placement studies are needed for intercrop systems in relation to soil type, soil fertility status, and moisture supply. Identification of intercrops and spatial arrangements that may result in greater smothering of weeds would be an important consideration for the intercropping system.

Survey of the existing literature has revealed that relatively little work has been done on the organic and inorganic nutrition of pigeonpea. Fertilizer response studies have generally given inadequate attention to soil tests, and no information exists on critical concentrations in soils or plants for different macro- and micro-metabolic nutrients. Responses to fertilizer nutrient elements are complicated by the interaction of nutrient deficiencies and/or toxicities with the symbiotic nitrogen fixation. With the intensification and diversification of cropping systems, more nutritional problems are likely to arise, and an understanding of the mineral nutrition of pigeonpea is essential to overcome them.

In conclusion, the following areas need greater emphasis in research:

1. Evaluation of various nontraditional systems of sole cropping of pigeonpea in relation to existing cropping systems in different areas. Identification of the areas where such systems could be introduced.
2. Development of appropriate agronomic practices for sole-crop pigeonpea for these nontraditional areas. Particular emphasis on plant density, spatial arrangements, fertilizer application in relation to soil characteristics, and water management.
3. Evaluation of various alternative intercropping systems for their productivity, economic superiority, and practical feasibility.
4. Development of information on optimum plant density, spatial arrangement, and moisture and nutrient removal pattern for different genotypes of the component species in the intercropping system.
5. Evaluation of ratooning of pigeonpea as a

practice in sole as well as in intercropping systems, and fertilizer and pest management for the ratoon crop.

6. Studies on the genotypic adaptation to temperature and photoperiodic condition and establishment of relationships between the agroclimatic factors and the regional productivity of pigeonpea.
7. Determination of critical concentrations for various macro- and micro-nutrients in soil and plant and development of fertilizer use recommendations based on these.

Entomology

H. F. van Emden*

In their paper, "Pest management in low-input pigeonpea," Dr. Reed of ICRISAT and his associates gave the results of a sample of over 1000 fields and reported that losses from pests averaged about 48% nationwide in India. This paper realistically stresses the constraints on pest management in pigeonpea farming in India, where less than 5% of the farmers appear currently to be using insecticides. I gather from subsequent conversations that many people thought that the second paper in the entomology session, "Alternative approaches to *Heliothis* management," by P. Blood, was a little ahead of the pigeonpea situation in India in its approach to pest management of *Heliothis.* I invite you to compare Dr. Reed's and Dr. Blood's papers at your leisure — you may not find them as divergent as you think! The technology of pest control is remarkably similar in both papers. In his verbal presentation, Dr. Blood emphasized the technology at the expense of the synthesis, but this synthesis is in his written version.

I would certainly recommend to you a study of the section on decision-making. Entomologists can research the options, but the synthesis is a decision exercise that involves people from many other disciplines as well, particularly rural economists, cropping systems scientists, and plant breeders; also perhaps, mathematicians and even politicians.

The rest of the agricultural community cannot expect the entomologist to come up with an answer when they themselves manipulate all the constraints on the system within which the entomologist is working. The audience at Tuesday's entomology session must have included members of nearly all the disciplines I mentioned, and the points were clearly set out by Dr. Reed and Dr. Blood. I hope they were taken. My own experience of conferences certainly is that my personal attitudes are affected by what I hear from *outside* my own specialism, and that such influences are the main advance that meetings such as this engender.

For this critique and synthesis, I do not propose to discuss the papers on entomology individually or in order, but will discuss broad topics raised at this workshop in relation to future progress and research.

Resistant Varieties

Development of resistant varieties is clearly the area of most intense current effort, and the entomologists involved held out little hope for a resistant pigeonpea cultivar to solve all the farmer's problems; no one queried my estimate of a 15 to 20% contribution to pest management from plant resistance.

Indeed, I am prepared to argue that the main entomological result of cultivar screening by other disciplines has been to put the clock back in pest control of pigeonpea on the research stations, and that screening for resistance to pests by entomologists has not been able to halt this process. The plant breeder's concept of a seed-based technology for low-input situations should perhaps not distinguish between determinants of yield in favor of those only revealed under insecticide protection when selecting cultivars for the entomologist to test. This point was made by Dr. Byth this morning, and certainly appears to have been taken at some, but not all, breeding centers.

The oft-repeated cry was that resistance to a pigeonpea pest often showed in a trial, but could not be repeated in a subsequent trial and certainly rarely in other regions of India. Of course, this is partly a problem of statistics, using a 1 in 20 chance for significance tests, confounded by inequality of the variation between cultivars contributing to a pooled standard error. Thus, even if all the plots were identical, rather more than 1 in 20 would appear significantly more resistant than the susceptible check. But there is more to it than that. The insect does not recognize genes; it recognizes

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mechanisms, morphological or biochemical, that are variable according to the environment in which the gene finds expression. This means that selection for pest resistance for breeding into desired cultivars must remain a regional decision. Equally, it is quite possible that cultivars rejected in screening for resistance at one center might have expressed valuable resistance in other regions if exposed to multilocation trials. Certainly understanding of the mechanism of resistance of a cultivar, especially of biochemical mechanisms, allows a check to be made on environmental variability and would, perhaps more importantly, acceleratethe pyramiding of resistance. A combination of several inadequate resistance characteristics, if we know the mechanisms to differ, could perhaps produce adequately resistant cultivars, since the effects of different mechanisms combine geometrically rather than arithmetically.

Cultural Control

There was general agreement that, as far as possible, *Heliothis* has to be controlled prior to the larval stage, since the regional dispersal of the moth means that little is gained by suppressing local populations after damage has occurred. The network of traps being planned across India therefore deserves every encouragement and financial support.

One of the best leads appears to be to aim at synchronous flowering by the choice of the right varieties and the cooperative action of farmers across a large area; as suggested by Dr. Reed against both *Heliothis* and podfly. Intercropping is another cultural measure that has given spectacular, though often unexplained, pest reductions with other crops. Alas, Dr. Bhatnagar's careful work has shown that, if anything, the *Heliothis* problem is intensified in the sorghum/pigeonpea intercrop.

Biological Control

I would go along with Dr. Blood that indigenous natural enemies hold out more prospect than exotic introductions. All the reports at this conference suggest that levels of parasitism in pigeonpea are low, and I could find little enthusiasm in discussions for the levels of 10 to 20% that occur in farmers' fields. Strangely enough, I find a level of 10to20% full of exciting potential. I believe that parasites have evolved behavior that leads them not to endanger their food supply. Research effort on *why* parasitism of 10 to 20% is rarely exceeded is likely to reveal the secret of the parasite's success — for that is what it surely isl It is only our human biased applied viewpoint that classifies a stable low level of parasitism as a failure! We have to trick a parasite into accomplishing the unnatural, either by augmentation to upset the pest: parasite ratio or by cheating it in some other way. That the egg parasite of *Heliothis* does nottransferfrom sorghum to pigeonpea in an intercrop is a valuable clue. *OUT* discussions raised the novel suggestion of selecting pigeonpea cultivars for susceptibility to the parasite rather than for resistance to *Heliothis* Farfetched maybe; but the breakthroughs in pest management in other crops have sometimes been no less bizarre. At least it represents positive thinking about biological control, and was one of the few positive suggestions we came up with.

Insecticidal Control

I sensed a defeatism about the use of insecticides on pigeonpea. Some entomologists pointed to the negligible use by farmers and the uncertain economic benefit. Others, with equal defeatism perhaps, saw insecticides as the only solution, and urged us to climb aboard the familiar insecticide treadmill.

As far as the economics of insecticide use are concerned, the presence of a strong contingent at this workshop from the University of Queensland indicates that pigeonpea may not remain the monopoly of India, and that — in an international workshop perspective — thought has to be given to pest management on intensive pigeonpea systems. Moreover, the economics of pigeonpea growing for the farmer in India are unlikely to remain static, and Dr. H. P. Saxena gave us a clear picture of the changes in the status of the pigeonpea crop already taking place in certain parts of India and which have considerable entomological implications. Certainly market prices, the ceiling yield of cultivars, and even the major pests may change; a farmer may well be prepared to spend money protecting a yield approaching 1500 kg/ha.

It was clear from Dr. Chhabra's paper (volume 2, these Proceedings) that insecticides for use on pigeonpea are being screened in India. Strangely, although several compounds gave excellent control of a pod-borer complex causing over 40% damage, there was remarkably little increase in yield. Thus a reduction of damage to 6.3% by carbaryl gave no significant yield increase! This suggests that attention should be paid to the sensitivity of the pigeonpea plant to insecticides. Dramatic leaf abscission or scorching would have been noticed by Dr. Chhabra; thus it is phototoxicity, without visible symptoms, that can be such an important component in the economics of spraying.

Those who advocated the insecticide road as the only alternative for higheryielding cultivars were almost echoing Rachel Carson's famous seven words in *The Silent Spring* — "We stand now where two roads diverge" — except that she was urging us in the other direction, to abandon insecticides in favor of plant resistance and biological control.

I happen *to* believe that new cultivars will inevitably bring the insecticide era to pigeonpea, but equally I believe— I must admit, with fanaticism —that those seven words by Rachel Carson, "We stand now where two roads diverge," are the most misleading words in the literature of applied entomology.

The words "pest management" have been used frequently at this workshop by entomologists to describe a nebulous goal at the end of an unknown road. It is actually far more practical to grasp the concept of its antithesis— "pest mismanagement."

If there is a partial component of plant resistance as well as some ambient biological control, it is clearly "pest mismanagement" to use pesticides for the total control effort. That is the road to ever-increasing doses and ever-increasing frequency of application until a yield disaster inevitably occurs. Both Dr. Reed and Dr. Blood in their papers warned of the folly of reliance on pesticides. That this is not just idle prophecy is illustrated by a short communication to this workshop by Dr. Pflucker in Peru. Pigeonpea in Peru is a minor backyard-scale crop, but *Heliothis* has never been a problem, largely because of high parasitism by the hymenopteran *Campoletis.* The widespread use of aerially applied insecticide on adjacent cotton fields has now markedly reduced the occurrence of *Campoletis,* just at a time when the pigeonpea acreage is likely to increase.

The 1959 Californian definition of "integrated control," the progenitor of modern "pest management," emphasized the selective use of insecticides to do no more than close the gap between the control achievable from other sources and the desired control level.

In many cases, it was found that the use of pesticide in a selective way promoted the level of biological control by changing the pest : parasite ratio on the crop. Biological control and pesticides, far from being alternative "roads," worked together in an effective and long-lasting partnership.

Many countries have sought the necessary element of selectivity in the pesticide itself. It is rather nice to be able to refer to this as the "soft" option — insecticides that allow many beneficials to survive have indeed been termed "soft" insecticides. Dr. Blood referred to these in his paper; endosulfan is the best known and most widely used such compound.

I would urge that the screening of insecticides for use on pigeonpea should put a premium on the discovery of "softness," though, as pointed out at this conference, "softness" for Hymenoptera could increase the incidence of the hymenopteran pod borer, *Tanaostigmoides.* The chemical to go for will almost certainly *not* be the one showing the best kill of the target pest in standard insecticidetrials. We were told that the synthetic pyrethroid insecticides are being tested in India for their potential on pigeonpea, though not with a view to introducing them in the near future, cost being an important consideration. I must comment that the broad spectrum and intense insect toxicity of this class of compounds, as well as the rapid tolerance to them that has appeared in target insects elsewhere, make the synthetic pyrethroids the kind of toxicant I would seek to avoid on pigeonpea, if at all possible.

I found it convenient to call the use of soft insecticides the "soft option," because the widespread adoption of compounds like endosulfan in pest management programs has rather obscured the original concept, which was the "soft" use of "hard" insecticides. This probably has the wider generality and certainly more diverse cases of success in the past. In effect, reducing the dose of "hard" insecticides can impart "softness," as can application in time and space in such a way that:

a. either the pest is contacted more efficiently than the parasite or
b. unsprayed reservoirs of beneficial insects remain within the crop.

The ways in which "softness" has been achieved in other crops are as varied as the crops themselves, and have involved generally applicable concepts such as spraying at a specific time of day or very ingenious solutions only appropriate to the particular situation. The only thing common to the solutions has been remarkable simplicity! For example, two general approaches obviously worth trying with pigeonpea *are* the restriction of pesticide to the pod-rich terminals or spraying strips, alternated with unsprayed strips, across the field.

Thus, researching the potential of insecticide application is similar to the principle I have *suggested for choice of active ingredient: we* may actively be seeking inefficiency of application against the target pest if the final output of the pest management package leads towards fewer kilograms of active ingredient per hectare per year. This may mean selection of a particular plant type to provide the appropriate spray target; for the small-scale farmer, the package may even well need proofing against his attempts at efficient coverage.

Putting It All Together: Recommendations for the Future

I have been asked to make recommendations; I think I have already given a not inconsiderable number in discussing the four main pest management components that now need to be put together.

The remaining recommendations thus refer to this process, for (as I hope I have made clear) the pest management result stems more from the interactions between the components than the components themselves.

The fundamental problem in making specific suggestions for future research is that basic information on the population dynamics of major pigeonpea pests is still often lacking. We do not yet know from where *Heliothis* arrives on the crop, or what alternative plant hosts many pests use, or how they bridge the dry season.

I therefore recommend that finance should be allocated to the necessary short-term research at universities and institutes, involving higher degree students or postdoctoral fellows. This is the only way to get the necessary information within a reasonable time span.

Secondly, I recommend that those already researching the control components pause to take stock and put together the components that they already have.

Each geographical area should select its own best cultivars, compromising between physiological yield and broad pest and disease resistance or escape. Low levels of plant resistance, if these are all that are available, should not be despised — often the marginal pest reduction so achieved has potentiated biological control to a surprising extent. Indeed, high levels of resistance can well lead to "pest mismanagement" if they make the crop inhospitable *to* beneficial *insects.*

Thirdly, the inevitable gap in control that remains can then be identified quantitatively and be related to the farmers' objectives and economic aspirations. If warranted, research on pesticides (as opposed to traditional field screening) isneeded to fill the gap — butno more than fill it — with selective *use* of pesticides.

You will, I am sure, have found these recommendations for integration optimistic and simplistic — they are indeed both! I do not underestimate the triviality of what I have said in comparison with the magnitude of the task of putting it into practice. Nor do I hope for an uncritical acceptance of such "instant wisdom" from scientists who have worked long and intensively on pigeonpea in the semi-arid tropics.

I do hope, however, that some of the ideas the entomological sessions of this workshop have stimulated in me will lead you to consider the way I have outlined as one way, to be compared with others, for escaping from the slight frustration I have felt among pulse entomologists this week at the conflict between the theory of pest management and the practice at farm level.

Pathology

J. P. Meiners*

Pigeonpea suffers from a long list of diseases, as do other pulses and edible legumes. Butler, working here in India, wasthefirstto publishon pigeonpea disease, as Dr. Nene pointed out in his paper. That was in 1906, and the disease was wilt. Between that time, nearly three-quarters of a century ago, and the establishment of ICRISAT, mycologists and plant pathologists have built up a considerable body of knowledge about pigeonpea disease. This foundation of basic information, assembled mostly by Indian scientists but also by those working elsewhere in the world, has provided a firm base for the expanded research undertaken by ICRISAT. We must keep this earlier contribution in mind as we consider the present research programs here and at other institutions around the world.

We need much more basic information. Some areas of research remain untouched, and others have been dealt with only superficially. For example, there have been few definitive studies on pigeonpea diseases to determine their incidence and the extent of the damage they cause. (The same is true for most crops, including cereals and other edible legumes.)

Such studies are essential to establishing the research emphasis for diseases of any crop; thus it is heartening to see that several are being conducted for pigeonpea diseases.

Several interesting papers were presented. One reported on extensive disease surveys in the pigeonpea area throughout India during the period 1975-1980, conducted by pathologists at ICRISAT in cooperation with colleagues from agricultural universities. These surveys confirmed earlier observations that wilt and sterility mosaic are the most widespread and damaging diseases in India, with Phytophthora blight, Macrophomina stem canker, and yellow mosaic moderately serious in some states. Some ten other diseases were present but of minor importance. Such surveys not only indicate the relative importance of diseases, but theirdistribution aswell — information that will be valuable in determining the type of resistances needed for specific areas, particularly so to state pathologists who find such surveys difficult to do on their own.

In another paper, ICRISAT pathologists found that reduction in yield due to sterility mosaic is directly proportional to time of infection, i.e., the earlier the infection, the greater the loss. This is to be expected, but these are the first data documenting this fact. Another paper reported results of tests showing that the wilt *Fusarium* can survive in pigeonpea stubble in Vertisols for 2.5 years and in Alfisols for 3 years—information basic to stabilizing cropping systems to minimize losses from wilt.

Such studies as these, which are basic to the understanding of the extent, nature, and, ultimately, the control of pigeonpea diseases, should continue at ICRISAT Center and be extended to other regions if a meaningful global pigeonpea disease program is to be forthcoming.

I would also recommend that studies on losses due to diseases and insects, carried out at ICRISAT and other institutions, should involve interdisciplinary teams, including economists. For example, at CIAT, an economic analysis by staff members indicated that several diseases and the leaf hopper, *Empoasca,* were the major causes of poor bean yields; this resulted in very high priority being accorded to breeding for resistance. Similar studies with pigeonpea would not only document the extent of losses due to disease, but also aid in determining the value of control procedures developed by ICRISAT scientists and cooperators.

Continued monitoring of the disease situation is needed to determine the impact of new cultivars, new farming systems, new ideotypes, etc., and should involve observations and measurements in experimental situations, demonstrators' fields, and farmers' fields. While pathologists should do this systematically, they can be alerted and aided in disease observation by entomologists, agronomists, and phys-

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iologists, as well as by extension workers. Such monitoring can determine the impact of new technology on disease incidence and also help to work out new disease problems real or potential.

The disease surveys carried out in India, the reports of ICRISAT pathologists' visits to Africa and other areas, and the review of pigeonpea diseases in the Caribbean all point up a problem in international improvement of pigeonpea: major diseases vary from region to region, influenced by climatic, edaphic, and biotic factors. An international center at one location in one country cannot solve the pathological problems of pigeonpea grown in diverse environments, even if major diseases were the same in all parts of the world.

Thus the extending of ICRISAT disease control programs to other regions, as has been done for the cereals program, is highly recommended. At the same time, we have received information at this workshop indicating that diseases vary in importance and in pathogenic specialization even within India. Because of this, the use of satellite locations in India and close cooperation with state pathologists must be continued by ICRISAT pathologists.

Now let us turn to a different aspect of research on disease control. Because the main target group of the research must be the small farmer with limited resources, the options available are restricted. Essentially the main viable method is that of breeding for disease resistance, and in relation to this, the development of effective screening methods is of paramount importance. The ICRISAT programs for screening and breeding for disease resistance — detailed in several papers at this workshop — are impressive because of (1) the nearly 100% infection obtained, (2) the size of the nurseries and the amount of material being screened, and (3) the presence of high levels of resistance in both germplasm and breeding materials.

However, I am sure that pathologists realize that breeding for resistance is not without its limitations and pitfalls. One is the danger of genetic homogeneity. The classical example of this is the southern com blight epidemic in the USA in the early 1970s, where the use of cytoplasmic male sterility was linked to blight susceptibility and nearly all of the U.S. maize crop became susceptible to the disease. learned upon arriving here that cytoplasmic male sterility has been found in pigeonpea. It must be used with caution!

Breeding for resistance itself can narrow the germplasm base. This has happened in *Phaseolus* beans, for example, through the very wide use in breeding programs of a single source of resistance to bean common mosaic virus. However, ICRISAT scientists, because they are screening a large pool of germplasm, should be able to locate diverse genetic sources of resistance to provide a broad base of resistance genes.

Related to avoidance of genetic homogeneity is the problem of breeding for a stable type of resistance. Only a few studies on the genetics of resistance in pigeonpea have been published, and all indicate an oligogenic or specific type of resistance. This is not to say that a simply inherited type of resistance is not stable. For example, the oligogenic resistance to bean common mosaic virus — quite a variable pathogen — has held up for more than 50 years in *Phaseolus vulgaris.* Moreover, as Dr. Swaminathan pointed out in his keynote address, specific resistance can be rendered more stable through such techniques as gene pyramiding, multilines, and sequential release of cultivars. Dr. Sharma mentioned in replying to a question that with both wilt and sterility mosaic, resistance may be conditioned by multiple alleles orgenes; if this proves true, it might make for a more stable type of resistance to those two diseases.

It appears that the major pathogens of pigeonpea are variable, in that pathogenic races have been found. With these pathogens, which include the most important ones — wilt, sterility mosaic, and Phytophthora blight—a general or nonspecific type of resistance should be identified and used. We have reason to feel that general resistance is available in most pulse crops, including pigeonpea, but is very difficult to identify. However, with the development of appropriate screening techniques and the use of suitable breeding methods and genetic analyses, general resistance probably can be identified. The presence of the wilt organism in plants of resistant lines identified at this Center may indicate that a general type of resistance is involved. Conversely, differential reaction to races may indicate that specific resistance to wilt is involved. International nurseries can be of considerable value in screening for resistance to diseases in various parts of the world, and can also identify variability in the pathogens. I would urge an expansion of the ICRISAT international disease nursery program. However, as others have already pointed out, international nurseries, while on the whole beneficial, can result in a reduction in genetic variability, and pigeonpea workers should keep this in mind as they use resistant material identified in these nurseries.

In reviewing the literature on the genetics of disease resistance in edible legumes, I found that there is little information available on the inheritance of resistance. Such information is essential to providing effective and stable disease control through genetic means and for applying proper breeding methods. Therefore, I would urge that inheritance studies be carried out in conjunction with breeding for resistance.

I note that several of the international institutes charged with research on edible legumes, including ICRISAT, have initiated such studies, and I would urge others to join in this interdisciplinary effort.

To summarize, I have four recommendations for future research on pigeonpea pathology; I feel these are pertinent to both international and national programs.

1. Pigeonpea pathologists, both at ICRISAT and elsewhere, must continue the basic research on pigeonpea diseases that will form the foundation of control strategies; not ivory-tower research but practical basic studies on incidence and losses, epidemiology, identification and characterization of causal agents, role of nematodes, disease interactions, etc.
2. Pathologists and breeders must continue to give first priority to developing of genetic resistance, while at the same time avoiding the problems that this type of control can generate. Secondarily, they should investigate alternative methods of control that will supplementthe resistance and study integrated control approaches.
3. Interdisciplinary efforts should focus on solving disease problems; if maximum progress is to be made, pathologists must work closely with breeders and geneticists, entomologists, physiologists, agronomists, and others.
4. A regional and global attack should be made on pigeonpea diseases, ICRISAT taking the lead in fostering this wide effort. However, national programs cannot sit back and let ICRISAT do it all. We Phaseolus pathologists look to CIAT for information materials, and assistance in research on bean diseases, but we all intend to continue our own particular programs of research as well. Pigeonpea pathologists in national and state programs should have this same relationship with ICRISAT.

In conclusion, I would like to say that only a few years ago, very little was known about the diseases of pigeonpea, their distribution, epidemiology, relative importance, and control. However, through the efforts of scientists in pigeonpea-growing regions across the world, a considerable body of knowledge is being accumulated that will solve many of the disease problems that limit pigeonpea production. We still have a long way to go, but this knowledge— plus the progress being made in other disciplines in pigeonpea production and use — should allow this crop to assume its proper place in the nutrition of the human race.

Utilization

H. A. B. Parpia*

It is well known by now that almost a third of the population of the developing countries suffers from malnutrition. There can be no question of improving the quality of life in these areas without improving the quality of the diet. Therefore, grain legumes, which are an important source of protein, must receive special attention, and pigeonpea offers great promise for improvement in both quantity and quality.

Pigeonpea occupies a very important place in the largely vegetarian diet of India, which is the biggest producer of this legume (Table 1). It is appropriate, therefore, that ICRISAT should have convened this workshop on pigeonpea in

Table 1. World pulse and pigeonpea production, 1970—1980.

	1970	1974	1979	1980F[a]
		Total pulses		
World				
Area harvested (000 ha)	68 831	71 804	72 303	73 261
Yield (kg/ha)	701	672	680	673
Production (000 tonnes)	48 225	48 230	49 141	49 279
		Total pigeonpeas		
World				
Area (000 ha)	2 982	2 999	3 000	2 951
Yield (kg/ha)	684	541	703	684
Production (000 tonnes)	2 039	1 622	2111	2017
Africa				
Area (000 ha)	214	241	252	255
Yield (kg/ha)	593	565	589	599
Production (000 tonnes)	127	136	149	153
North and Central America				
Area (000 ha)	24	28	2	9
Yield (kg/ha)	1603	1 411	2 500	2 222
Production (000 tonnes)	38	40	5	20
Asia				
Area (000 ha)	2 723	2 723	2718	2 656
Yield (kg/ha)	703	530	713	687
Production (000 tonnes)	1913	1 442	1 938	1824
India				
Area (000 ha)	2 655	2 646	2 663	2 600
Yield (kg/ha)	709	532	719	692
Production (000 tonnes)	1883	1408	1 914	1800

Source: FAO.
a. FAO estimates include China.

* Food and Agriculture Organization, Rome, Italy.

India and in collaboration with the Indian Council of Agricultural Research, which has a long tradition of work in this field.

During the workshop we have discussed genetics, breeding, entomology, pathology, and various other aspects of improving pigeonpea production. All of these, however, are geared to the same end: utilization. All of you here are interested in producing pigeonpeas for utilization.

Several papers were presented on this topic; I will not attempt to summarize them but will rather make some general observations. We have talked about increasing pigeonpea production by expanding area cultivated and increasing yields. Even with present production levels, however, availability of all legumes can be substantially increased by preventing or reducing processing losses and improving postharvest handling and storage to prevent insect infestation. With no additional demands on land or inputs, it should be possible to raise total availability of grain legumes by 5 to 15%. For example, one generation of a bruchid in 8 months can eat about 60 times its own weight of food. When infestation is heavy, the result is obvious. Secondly, studies in chickpea show — and the figures for pigeonpea are similar — that if kernel damage is 2%, the milling yield by the modern process is 82%; when kernel damage is 15%, milling yield is only 65%; 17% of good food is lost immediately.

The other major problem in utilization is to improve the quality of the diet. Grain legumes contain many essential amino acids, though they are not always well balanced. A study of typical basal diets in India was carried out to determine exactly what amino acid deficiencies occur in them. The moment these were made up, a distinct improvement in nutrition could be observed. A great deal of dietary deficiency is found among children up to the age of five. There is a great need, therefore, for nutritious weaning foods. Although some are marketed, these products are meant for the upper income groups. The urgency is to develop typical traditional foods, which can be made in the villages by the rural people themselves. To supplement the amino acids, sesame can be used in areas where it is accepted, or fenugreek, an excellent source of methionine, can be used where its bitter taste is not considered objectionable, as in Egypt.

Here again, improved processing and storage facilities will also help improve diet quality. As a result of just 4 weeks of insect infestation, the protein efficiency ratio drops markedly; if such infestation could be prevented, the diet would automatically improve.

Based on these observations and the discussions and papers at the workshop, I would recommend that immediate attention be paid to the development of:

1. Improved processing techniques, especially on the rural and home scale. The most durable agricultural produce is not food unless it goes through some kind of processing. With increasing urbanization, there is also a growing demand for processed legume-based products, in addition to dhal, and this demand should be recognized. Future research should seek to improve milling characteristics of pigeonpea by breeding varieties with larger seeds, round grain, and a thinner seed coat. At present, as two or three studies pointed out, the husk constitutes about 14%; if this could be cut to half, it would mean a 7% increase in the availability of pigeonpeas.
2. Improved storage facilities to prevent insect infestation, which currently reduces both quantity and quality of stored pigeonpeas. Some good work has been done on this using activated clay, which can reduce infestation almost 100%. Simultaneously, breeding of resistant varieties is also necessary.
3. Improved nutritional quality, taking into account the total amino acid picture. Antinutritional factors should be reduced through breeding, as has been done with *khesari* dhal (*Lathyrus sativus*). Here there is an urgent need for collaboration, not only horizontally, among breeders, but also vertically, with those involved in conservation, product manufacture, and utilization.
4. Better cooking characteristics. With the increasing cost of fuel, it has become an important requirement to develop varieties that have better moisture absorption capacity. If, for example, magnesium and calcium content of pigeonpeas can be reduced, they cook much better.
5. A better distribution system. For example, in India, as Dr. von Oppen pointed out, the

demand for pigeonpeas in the south is much greater than in the north. Dietary surveys also show that while average consumption of grain legumes in the north is 60 to 80 g, it can be as low as 15 g in the south. Increasing availability of pigeonpeas in the south could help remedy this situation.

Finally, I would like to congratulate the organizers of this workshop for their effort to bring together all the disciplines involved in pigeonpea production and utilization. This is the only way we can identify our problems clearly and work towards resolving them.

Breeding

D. E. Byth*

The presentation of a critique and synthesis on plant breeding for a Workshop such as this on pigeonpea is a daunting task. It is particularly complicated by the fact that, as I have argued in an earlier session, plant breeding is the central discipline in genetic improvement of crop plants. Plant breeding has its own scientific bases and fundamental research interests, but it cannot by itself mount an effective, sustained, and objective scientific attack on the breadth of crop production problems. Plant improvement is the central objective of our work, and is a genuinely multidisciplinary activity which involves all the aspects of the plant sciences discussed at this Workshop. Plant breeding is simply the conduit through which much of the contribution of other disciplines to genetic improvement is siphoned.

Consequently, since plant breeding practice is basically the technology by which we implement all genetic improvements, and since plant improvement is the primary rationaleof applied biological research, I have used these considerations to derive the theme for this critique and synthesis of plant breeding and its contributions to pigeonpea improvement. The theme is:

"Constraints to the genetic improvement of pigeonpea for production and adaptation"

In following this theme, I will attempt to touch on the genetic and breed ing aspects of all of the major topics of pigeonpea improvement with which this Workshop has dealt This is necessary because the central position of breeding in the context of plant improvement makes it necessary to consider the broader picture.

As a result, the scope of this paper inevitably is very broad. I will therefore be obliged to deal with the matter in generalities to a large extent, and I will not be referring to the specific contributions to this Workshop.

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The Challenge of Pigeonpea Improvement

In his keynote address, Dr. Swaminathan made it perfectly clear that India intends to expand substantially the production of pigeonpeas. Other papers presented to the Workshop clearly indicate this is also an expectation in a number of other countries.

This resolution to expand pigeonpea production worldwide is not the result of scientific decision. Presumably it is a political decision, based largely on economic and social considerations and reflects an integration of many opinions, pressures, and options including scientific judgment of the potential for improvement of the species. Nevertheless, given that the decision to expand production has been made, much of the problem of its implementation becomes the concern of the scientist, and the decision does provide important knowledge and guidance to the scientist. For example, it means that at this Workshop we have been discussing the improvement of a crop that will develop and expand substantially in importance during our time as scientists; that is, pigeonpea improvement is a real and active scientific challenge with which we must cope, rather than a static or contracting problem. Furthermore, Dr. Swaminathan also indicated thatthe increases in production are expected to come both from improved productivity in existing areas and from expansion of production into new areas. This helps us to define the challenge as one of increasing productivity in existing uses and of extending the adaptation of the crop into new areas and uses.

As scientists, our challenge is to determine how to bring scientific expertise to bear on this problem in the most effective manner. This is a complex and fascinating task. With very few exceptions, the food legumes are under-researched crops and in fact are relatively primitive in their development for domesticated agriculture. The pigeonpea is probably *near* the extreme in this context — despite its long history of cultivation, it remains fundamentally a wild plant of which we have relatively little scientific understanding. This is both an advantage and a disadvantage. Since the species has been subject to little deliberate improvement, it should be relatively easy to make substantial genetic and environmental gains in productivity. This Workshop has demonstrated this is so. However, sustained advance in productivity and adaptation will only result from a commitment to obtaining a real understanding of its growth, development, and adaptation.

This is the real challenge posed to us as scientists working towards pigeonpea improvement. This Workshop has made it clear that substantial advances have been made during the last decade in our scientific knowledge of pigeonpea. Our problem is not only to continue this development of knowledge, but also to ensure that problem-orientation is foremost in our minds — that is, that our research is orientated to the definition and resolution of the real production constraints and problems of pigeonpea, so that the society as a whole can benefit from their investment in our work.

The Production System — The Central Issue in Plant Improvement

I have argued in a previous paper here that the production system is the central issue in the improvement of any agricultural species. It is unnecessary to repeat the arguments. Rather, I will simply restate the point that virtually all scientific knowledge of agricultural problems is system-specific. There is no reason to believe that any estimate we make has generality beyond the system within which that estimate is made. The estimate *may* have application in other situations, but that remains to be proven. We can attack this by modeling or by empirical testing, and this is a valid and important scientific endeavor. It is our responsibility as scientists to ensure that the estimates we make are accurate, precise, and relevant; that we document the situation within which the observations are made; and that we consider closely the meaning of those estimates beyond the immediate test situation.

In this context, I consider that this Workshop has been less effective than it could have been. This is primarily because for many situations, we have not identified a frame of reference on pigeonpea culture that will allow us to extend the results we obtain to other circumstances and situations. The production system is such a frame of reference because it is the central issue in pigeonpea improvement. It provides the focus for definition and integration of research, and for extension of the results of that research to other situations and to the farmer's field. In other words, it orientates our diverse research interests towards understanding the real limitations and constraints to production in particular systems, and this can only be useful in developing an improved understanding of adaptation of the species.

This theme will recur throughout this paper. The basic argument is that a primary constraint to the improvement of pigeonpea has been in our minds — our failure to conceive of an acceptable general framework within which to develop integrated research on this crop. I believe the production system is that framework.

Breeding and Genetics

It is not possible in this paper to address each of the topics of importance in the genetic improvement of the pigeonpea that were raised at this Workshop. Rather, I will consider some of the major areas of the discipline, and make some general observations on them in the general context of the theme — constraints to the genetic improvement of pigeonpea for production and adaptation.

Limitations to the Genetic Base

Basically, I am referring here to the question of availability of genetic variability in the species, and the extent to which our use of it is restricted.

As far as I can see, there appear to be few documented cases of lack of genetic variability in *Cajanus cajan;* one possible one was the absence of demonstrated resistance to witches' broom disease, and perhaps others exist. For the quantitative, phenological, and agronomic characters of interest, there appears to be a huge range of variation available, and the simple fact is that we have hardly commenced to tap it.

Equally, the only real restriction to our access to that genetic variability is the wide differences in phenology that can complicate hybridization, but even this hurdle is a minor *one* that can be overcome.

Consequently, one must concludethat access to genetic variability is, in most characters, excellent or at least adequate. This automatically leads to the further conclusion that there is little justification for the conduct of mutation breeding in this crop at this time. Of course, the academic study of mutagenesis is an entirely different question, and should not be discouraged as it can supply useful basic information.

The question of the limitations to our use of this genetic base in plant improvement is a very different one. If we contrast the genetic base of production vs plant improvement, a most disturbing picture emerges. Most actual production in India and Africa is based on landrace varieties, which implies that the genetic base of production is very broad indeed. However, the rapid expansion of the crop in Rajasthan and Punjab is based almost exclusively *on* UPAS-120 and T-21, respectively. Thus a picture emerges of a drastically narrowing genetic base regionally as a result of plant improvement. The cause of this is unclear to me, but I can see little justification and considerable dangers in these apparent beginnings of a trend to a very narrow genetic base of production.

With respect to the genetic base in plant improvement, I can only reflect my impressions from the ICRISAT program and particularly the early-maturity program. Again here, it is clear that the genetic base being utilized is extremely narrow. There may be good practical reasons for this, but it inevitably carries with it considerable risks. Genetic vulnerability to pest or disease attack or to susceptibility to particular environmental constraints is one of these risks. Similarly, there is already a suggestion of source limitation to yield in one population of large-seeded early pigeonpea. Narrowness of environmental adaptation could be a particular problem for certain germplasm. As a result of the active exchange of breeding material internationally, any problems induced by narrowness of genetic base may flow rapidly to the national and regional programs, and this is particularly disturbing.

In short, a picture emerges of a very broad genetic base being quite rapidly, and rather inexplicably, narrowed very drastically as a result of plant improvement activity. This situation needs to be corrected as a matter of urgency.

Limits to Genetic Knowledge

Despite a substantial amount of work internationally, our knowledge of the genetic determination of the various characters of pigeonpea is truly limited. There is need for much work in this area. I will mention only a couple of aspects that appear to be of particular importance as a result of this Workshop.

Inheritance of Phenological Response

Phenology is the central character underlying ecophysiological adaptation, and it is most important that we gain a better understanding of its genetic control. Breeders are required to manipulate phenology to fit each production system, and this requires a detailed understanding of its inheritance.

This is not a simple exercise. It is increasingly clear that phenology in pigeonpea reflects complex responses to photoperiod and photoperiod x temperature interactions. We have much to learn about these responses in a descriptive phenotypic sense, let alone their genetic control. For example, Moses Onim reports that most, if not all, ICRISAT material is very early flowering in Kenya, whereas locally adapted material is quite long season. Clearly this infers a basic genetic difference between these populations in the genetic determination of phenology, but whether this is due to genetic effects influencing photoperiodic response or temperature-mediated promoters and inhibitors is not known. We urgently need to understand better the genetics of flowering response in pigeonpea.

Quantitative Genetic Inheritance

This is a huge subject area which is of fundamental importance in defining breeding procedures for improvement of quantitative characters. Only a few of the more important points can be mentioned here.

GENE ACTION AND INHERITANCE. There is a basic dichotomy among pigeonpea breeders in the literature and at this Workshop regarding the form of gene action operating to determine many of our important agronomic characters — one group's work infers predominance of additive genetic effects; the other shows predominance of nonadditivity. This is a most disturbing disagreement because it cuts at the fundamental bases of breeding and complicates all discussion of breeding objectives. There is urgent need by both parties to reconsider their experimental evidence and the correctness of their inferences.

One basic aspect of breeding influenced by this disagreement is the choice of parents and of type of cultivar. This decision is difficult enough for breeders *at* any time — in fact it is probably the most challenging task in breeding and there are few fundamental guidelines. An unnecessary disagreement on the modes of gene action for quantitative traits simply complicates it further.

INTERRELATIONSHIPS AMONG CHARACTERS. Genetic correlation among characters is due either to linkage of genes on the chromosome or to the presence of genes that have pleiotropic effects. The basic effect of genetic association is to reduce recombination of the characters. Since our primary interest is in recombinants, we need to know much more regarding genetic association among quantitative characters in pigeonpea, and the causes of it. These associations can greatly help, or greatly hinder, the attainment of genetic improvement.

However, I again emphasize that all estimates of quantitative genetic parameters are inevitably specific to the population being tested and to the environment of the test. For this reason, considerable caution is needed in the derivation, interpretation, and extrapolation of estimates of mode of inheritance, value of parents, interrelationships among traits, etc. In all experimentation, we can arrange to get virtually any answer we desire, simply by choosing particular parents or using particular test regimes. One way in which we can make our estimates and scientific inference more meaningful is to define the particular production system being addressed, and to restrict our inferences to that parental material and that cultural environment. In this way, our estimates should reflect more reasonably the genetic reality for that situation of interest in plant improvement.

Breeding Methodology and Mating System

Pigeonpeas can be self-pollinated but may exhibit considerable outcrossing as a result of insect activity. As a result, breeding methods in this crop may be either the classic set-piece designs of the self-pollinated crop (pedigree, bulk etc. systems) or the population improvement designs (recurrent selection, etc.) that have been most effective in the improvement of cross-pollinated species. At present there are no clear guidelines regarding the optimal approach for pigeonpea, but most contemporary programs are designed to exploit the tendency towards self-pollination.

I consider flexibility of use of breeding methods is necessary. In view of the high incidence of natural outcrossing by bees, it would be foolish to neglect this economical method of gaining recombination. Effective population improvement may be attained by the use of carefully designed schemes involving open-pollination plus genetic control of reproductive biology via genetic male sterility and/or mechanisms that enforce self-pollination. It is probable that these sorts of mating schemes will become increasingly important in pigeonpea improvement because of the wide range of phenology and habit in the species, and the need for introgression of genes across this range.

Breeders are fortunate in pigeonpea in that the attainment of genetic control of the mating system appears to be relatively simple. Thus recombination is not grossly restricted by the nature of the mating system as in many other species, and most breeding methodologies can be applied. Ingenuity is required to devise the most effective methods for recombination and selection in pigeonpea.

Limits to Exploitation of Heterosis

The exploitation of heterosis in pigeonpea was discussed in an earlier session. It is clear that hybrid cultivars show real promise, and heterosis needs to be pursued actively in this crop. However, certain clear limitations to this process exist, and are mentioned briefly here:

- restriction of the sources of male sterility available, both in genetic diversity of source and of phenology within particular sources;
- unavailability of a method of obtaining a pure-breeding male sterile line; cytoplasmic male sterility would accomplish this;
- restriction of our knowledge of the magnitude of heterosis and factors underlying its expression in different habits and different production systems;
- restriction of resources available for evaluation of combining ability on a large scale in order to identify high combining combinations of parents.

Limitations to Environmental Adaptation

As for any species, fundamental limitations to the environmental adaptation of pigeonpea must exist. Some aspects of this were discussed by Dr. Virmani, particularly with respect to the climatic environment.

However, concepts of adaptation and its limits need to be treated cautiously in plant improvement. Commonly, the restrictions to adaptation claimed to exist for a species are in the mind of the observer rather than in the genes of the species, and may reflect limitations of experience or of the germplasm base. A component of the charter in pigeonpea improvement involves broadening the adaptation of the crop, and this requires an innovative and flexible approach.

Analysis of adaptation responses was discussed in a Workshop session and clearly is central to full exploitation of the genetic potential of this species. At this stage, there is insufficient understanding of the ecophysiological bases of adaptation of this species to allow effective definition of the fundamental constraints to adaptation. It is certain that pigeonpea production can occur in a very wide diversity of production systems, and the constraints to adaptation are likely to differ markedly between these systems.

Genetic/Breeding Aspects of Associated Disciplines

In this section, I will consider some genetic and breeding aspects of the other disciplines involved in plant improvement. This is necessary because breeding is the mechanism by which their contributions to plant improvement are translated into production reality.

Germplasm

Large germplasm collections exist internationally. The largest, at ICRISAT, includes some 8800 collections and is actively being expanded to develop into a world collection that can be exploited internationally. This is a major project and a massive exercise which has already proved to be of value to breeders and other scientists. Nevertheless, there are real problems with such a collection as far as breeders are concerned.

Scope

The present collection is predominantly of Indian origin and many countries are poorly represented. This needs to be corrected.

Exploitation

The usefulness of a collection in breeding depends on access to defined portions of it. This requires description and classification. This is relatively easy for qualitative characters such as disease resistance, color and shape of seed, leaf shape, etc. Quantitative characters are more difficult to describe because they are subject to genotype x environment interactions. At present, most phenotypic characterization occurs at Hyderabad, and this is quite inadequate to guide breeders in the use of germplasm worldwide in different production systems and environments.

More exhaustive characterization of germplasm is required. This is not a simple problem and it will be difficult and expensive to resolve. Nevertheless it must be done if the full potential of our germplasm resource is to be exploited.

Utilization

Utilization of germplasm collections is a complex subject, and the problem is not unique to pigeonpea. The genes within the collection must be accessible in a sensible way if the resource is to be used as a working collection.

The range of phenology in pigeonpea makes this a particularly important problem.

The related species offer another dimension to genetic resources. Many collections of *Atylosia* and other genera have been made, and some intergeneric hybrids have been possible. The potential contribution to pigeonpea improvement from this work is still quite unknown, but some promising prospects exist, e.g., pest resistance and cytoplasmic male sterility. Other physiological characters of importance may be derived from related taxa. There is a need for careful and sustained genetic research in this area, to extend our knowledge of genetic relationship among the taxa, and to capitalize on any potential for pigeonpea improvement by gene flow.

Cropping Systems

There has been considerable discussion of the various aspects of cropping systems for pigeonpea during this Workshop. However, I will restrict my comments to one aspect which poses particular problems to plant breeders, i.e., intercropping. This is the most common and most important production system internationally. As such, pigeonpea performance in, and improvement for, intercropping must be addressed by plant breeders. The problem is to determine how this may best be done, and there is considerable debate on this question.

Plant improvement for intercropping presents particular challenges for several reasons. The primary problem is that intercropping is a strategy that encompasses many different cropping systems. There is a huge diversity of intercropping, with variation both in the species used and in the agronomic practices adapted for it regionally. Furthermore, the physiological situation for each component of the system can change greatly across seasons, and even within a growing season, depending on the companion species and the environmental conditions. Thus the performance of each component of an intercropping system is a function not only of the physical environment but also of the other crop components of the system. In short, the other components of the system are integral and additional portions of the environment for intercropped pigeonpea, so that its performance reflects genotype x environment interactions that can be substantially more complex than those for sole cropping.

In principle, breeding for improved adaptation involves capitalization on favorable genotype x environment interactions and minimizing the impact of unfavorable interactions. While it is conceptually possibleto exploit favorable interactions between pigeonpea genotypes and a specific genotype of an intercropped species for a particular environment, the extrapolation of such advance across environments, managements, and intercropping systems is most problematical. Simply, the physiological causes of superiority of a genotype within an intercropping system are likely to be specific to that system.

Because of the complexity of intercropping, the question reduces to determining whether one should breed for intercropping or test fixed lines for intercrop performance. I have seen no evidence at this Workshop that would justify a formal breeding program for intercrop performance at this stage. Conversely, I can see strong justification for a program of testing of fixed lines for performance in the intercropping systems relevant regionally. This should incorporate determination of the degree of commonality of merit under sole and intercropping, and physiological analysis of the causes of this in particular cases.

Entomology

Clearly, pest damage can have a massive effect on productivity of pigeonpea and is probably the most important problem at the farm level. Breeders and entomologists can collaborate effectively to address this problem at three levels. First, crop scheduling in relation to the climatic and pest environment is possible by modification of phenology, in order to reduce the probability of exposure to pest attack. Second, good progress is being made in host plant resistance of pigeonpea. The results are sufficiently promising to justify more active use of specific germplasm in breeding. Third, exploitation of host plant tolerance is possible. However, the expression of tolerance will almost certainly vary drastically in different production systems, and this complicates its use. This is a genuine multidisciplinary problem which requires input by physiologists, entomologists and breeders to resolve the mechanisms for tolerance. Fourth, there is urgent need for involvement by entomologists in quantitative breeding programs to assist in the development of objective selection strategies that incorporate adequate screening for pest resistance.

Considerable progress has been made in investigating pest resistance in pigeonpea. Much more needs to be done. There needs to be an increased emphasis on multidisciplinary collaboration in this very difficult and important area.

Pathology

It is clear from the literature and this Workshop that excellent progress has been made in the identification and incorporation of genetic resistance to the major pigeonpea diseases. Nevertheless, a number of problems exist that *are* of concern to plant breeders.

New races of the important pathogens are likely to arise or be encountered regionally, and there is a need to seek additional genes for resistance to confront these challenges and to broaden the genetic basis of resistance. This requires joint action by pathologists, breeders, and germplasm resource personnel. Similarly, methods of exploiting genes for genetic resistance to provide a more durable form of resistance need to be investigated, e.g., gene pyramiding. Dr. Meiners has also indicated the need to consider generalized resistance in addition to the specific resistances. I support this and consider that work should be commenced in this area as a matter of urgency. Such research is complex, costly, and long term, and requires multidisciplinary input. As such, the resources for its development are presumably the responsibility of the international group at ICRISAT which should be able to provide the continuity of research necessary.

It is certain that new races of existing major diseases will arise and/or that existing minor diseases will attain greater importance in the future. Genetic control provides the only feasible solution, and there is a need for continued multidisciplinary attention in this area to address the problems on an international and regional basis.

Physiology

A proper understanding of the ecophysiological basis of adaptation and production is central to the conduct of effective plant improvement. In view of the limits to our understanding of the physiology of pigeonpea, and of the diversity of production systems for the crop, there is a need for intensification of physiological research.

Specific areas of research need to be addressed. The various production systems present quite different physiological challenges, and there is a need to develop a detailed understanding of the physiological limits of such systems and of the germplasm adapted to them. One of the most important and interesting characteristics of the pigeonpea is its perenniality. To date, this has received little attention by scientists, and the crop is treated as an annual in most situations. Evidence exists that perenniality can be exploited very effectively indeed in some cropping systems, and there is an urgent need for innovative research in this area to capitalize on this important characteristic of pigeonpea.

Other specific problems exist that require physiological study in order to support plant improvement— identification and exploitation of genetic differences in response to salinity, tolerance of water stress, response to soil fertility, physiology of flowering and its control for accelerated generation turnover, etc. Close collaboration of breeders, physiologists, and germplasm resource personnel is needed in this work.

Microbiology

This is a most troublesome area as far as genetic improvement of pigeonpea is concerned. There is variable response to inoculation, yet extremely high seed yields are possible in some situations without application of nitrogenous fertilizers. The evidence is circumstantial but suggests that the plant is capable of fixing substantial nitrogen, at least under some situations.

At present, research into pigeonpea microbiology has not reached the stage where it can be exploited genetically in plant improvement. Considerable scope exists for collaboration of microbiologists and breeders in research; for example, in strain x genotype interaction, selection for precocious or sustained nodulation, and for effectiveness of nodulation. However, quite basic questions on the importance of N fixation in the different production systems, and on our ability to select for N fixation, require investigation before practical breeding is feasible.

Seed quality

As for microbiology, this is a most disturbing area to me as a breeder. Effective plant breeding can be done only where clear and reasonably unambiguous objectives exist. It is clear from this Workshop that numerous aspects of quality — including visual appearance, cooking time, milling percentage, digestibility, protein quality and quantity, and mineral content — are considered to have importance nutritionally or economically. Despite this information, or perhaps because of it, I find the situation confusing in that no clear guidelines exist for the breeder regarding seed quality improvement.

It is a fact that selection pressure available to breeders is severely limited, and it must be allocated to areas most likely to be productive. Until a convincing case can be made for improvement in one Or a few specific quality factors, I must subscribe to what the Chairman of Session 9 inferred — that seed yield remains the primary objective now, and that specific quality characters should not be considered explicitly in contemporary breeding programs.

The concept of "vegetable-type" pigeonpea is equally confusing to me. Apart from a requirementfor large-seededness, I remain unsure what other quality characters, if any, are involved. Consequently, it is difficult to see a clear justification for the establishment of a "vegetable-type" breeding program. Seed size per se can and will be sought in contemporary breeding in any event, for reasons of potential market demand, yield potential, and homeostasis.

Considerable objective research is necessary to define more clearly the quality characters that require genetic improvement, and this is particularly so for vegetable usage and for processing. It is probable that pigeonpea researchers and processors in the Caribbean can provide considerable guidance in this area. However, in the meantime, formal breeding for quality is not justified.

The Future for Pigeonpea Improvement

At the end of a Workshop such as this, it is appropriate to consider the future — specifically, what is the future for genetic improvement of the pigeonpea?

I am most optimistic that we will be able to address the problems of genetic improvement in such a way as to satisfy the demands for expansion of this crop. Given an appropriate theme to direct and coordinate the research in plant improvement, it should be possible to exploit the tremendous potential of this species to increase its productivity and broaden its adaptation. I can even be optimistic that the position of pigeonpea in crop rotations with cereals will be improved.

It is important to consider the international aspects of pigeonpea improvement in this context. Most of this work is done at the local and regional levels, and generally in small programs with restricted resources. There is much one can do in that situation, and we should not see our work as being unimportant on the global scene. In practice, the implementation of improvements at the local level is the real contribution to improved production.

Nevertheless, while individual initiative at the local level can result in major advances, capitalization on that advance and its incorporation into other genetic material and production systems elsewhere is a difficult problem and requires a different approach.

There is no doubt that the primary factor in the long-term improvement of pigeonpea internationally is the ICRISAT charter program. At this Center, there is a body of committed and experienced researchers in all disciplines, and they have access to substantial resources for pigeonpea improvement. In order to maximize the effectiveness of this investment, we need two commitments. First, a commitment by local programs to make maximum use of the genetic and scientific resources available at ICRISAT. We would be most foolish not to do so. From personal experience, I can speak of the eagerness of all ICRISAT staff to collaborate, assist, and exchange ideas and material with local programs. We can exploit this resource and we have a responsibility to do so. Second, there needs to be a commitment by ICRISAT to attain effective international improvement in pigeonpea. This is their charter and their responsibility. It is a rather daunting responsibility, particularly in this sort of crop.

In the few years of active pigeonpea improvement research at ICRISAT, the Institute has demonstrated that commitment and has done much to establish effective international collaboration. ICRISAT can be proud of that. In India, ICRISAT has collaborated most effectively with the massive national program, and this has been of benefit not just to ICRISAT or India, but internationally, to all of us. The depth of resources and experience in the Indian program is invaluable.

At the same time, ICRISAT has a responsibility to address the improvement of pigeonpea in other countries also, particularly in Africa and the Caribbean. As our knowledge of the ecophysiological adaptation of pigeonpea expands, there is a continuing responsibility for ICRISAT to update and implement schemes that address efficiently the global problems of improvement of this crop.

As I have said, this is a most daunting task, and a major challenge. It will require continued and flexible reassessment of the problems and prospects for resolution. I have no doubt that the staff of this Institute and of the various national programs is capable of this task and will continue to respond to the challenge.

Appendix 1
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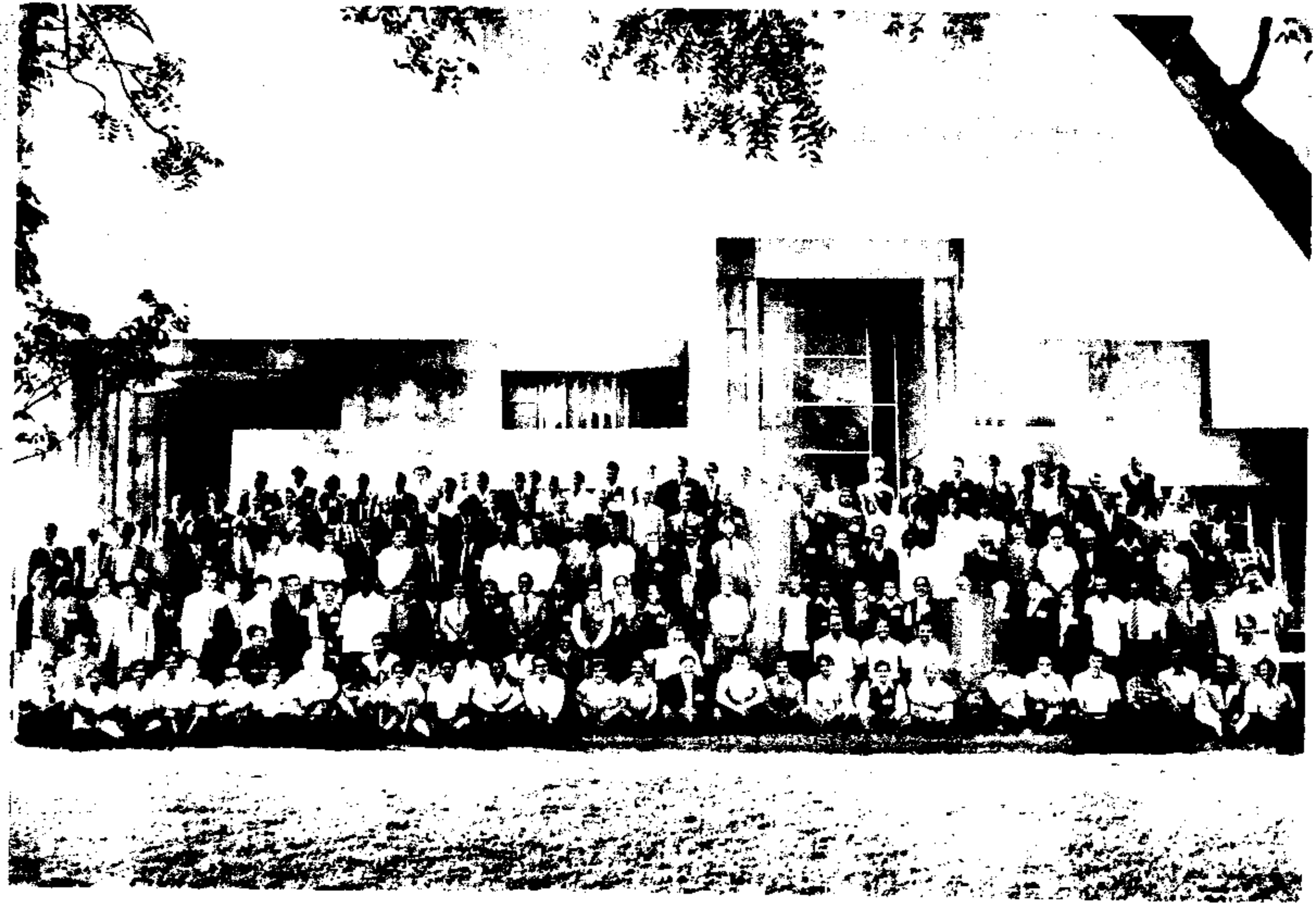

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