Agronomy/Physiology Research on Pigeonpea

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Contents

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Pigeonpea [*Cajanus cajan* (L.) Millsp], the fifth most important pulse crop in the world, originated in India. It is mainly a subsistence crop in the tropics and subtropics of India, Africa, south-east Asia and the Caribbean, but also an important cash crop in the West Indies. The crop is most commonly grown for its dry split seeds (dhal), which have a protein concentration of approximately 20-25%, but seeds are also eaten as a green vegetable. In these ways it is an important component of human nutrition particularly in vegetarian diets. One of the important attributes of the crop is its ability to survive and reproduce in environments chracterised by severe moisture stress and poor soil fertility.

Cultivation

Pigeonpeas are grown in a wide range of cropping systems. These can be broadly divided into long season, full season, and short season classes (Byth *et al.* 1981). The long season crops are usually sown around the longest day of the year and flower after the shortest day. This is the traditional system in northern India and parts of central India. The crop is commonly sown at low density with the onset of the monsoon in June or July, grows vegetatively throughout the monsoon season, flowers around January, and is harvested in March to April. Such long season pigeonpeas are usually intercropped with one or more other species (Willey *et al.* 1981). They are generally confined to frost-free areas and are grown on soils of high water holding capacity (Reddy and Virmani, 1981).

Full season crops mature earlier than long season crops, with sowing around the longest day. They flower in decreasing daylengths, and are harvested after the normal sowing time of winter crops. This cropping system is common in peninsular India, and involves intercropping with cereals or other crops. Such intercropping has advantages, namely, greater combined yields (pigeonpea + intercrop) per unit area than if the crops are grown separately and yield stability (Rao and Willey, 1980).

Short season cropping systems either involve short-duration cultivars which are more or less photoinsensitive and which mature relatively quickly regardless of sowing date, or depend on sowing several months after the longest day, when the more rapid flowering under short day conditions enables both photoperiod-sensitive and insensitive cultivars to be used.

In addition, pigeonpeas are grown as perennial 'backyard' plants in many tropical countries. They can also be used as a green manure or forage crop.

Seed germination

Germination is hypogeal. The seed has no dormancy and germination is generally good except under cool conditions. Studies in controlled environments have shown a broad optimum temperature range (19 to 43°C) for germination, with the most rapid growth of the seedlings occurring between 29 and 36°C (de Jabrum et al. 1981).

Flowering

Pigeonpeas are short day plants. Flowering is delayed by temperatures either below or above the range 20-28°C. Through a combination of photoperiodic and temperature effects, the time to flowering and maturity of pigeonpea cultivars varies according to the date of planting (Akinola and Whiteman, 1974). For example, in peninsular India, with the normal time of planting at the beginning of south-west monsoon in June or July, early cultivars mature in 4 to 5 months, medium cultivars in 5 to 6 months and late cultivars in 6 to 9 months. But when grown under short days in the cool postrainy season, planted around October, they flower sooner and their development is 'telescoped' in such a way that early cultivars mature in less than 4 months, medium in 4 to 4.5 months and late in 4.5 to 5 months.

The growth duration of a cultivar is one of the most important factors affecting its adaptation to a particular cropping system, climatic environment, and soil type. Therefore, it is important to classify cultivars according to their phenology; and ICRISAT breeders have so far recognized 10 groups on the basis of their duration and photoperiod response (Sharma, et al. 1981). One problem in making such a classification on the basis of performance at a single location is that the photoperiodic response is affected by temperature. An important effect of temperature on flowering seems to be reduction in the requirement of short days under relatively cool conditions. While considering the effects of temperature on flowering, it is important to know that floral initiation and rate of development of the floral primordia may be affected differently (Turnbull et al. 1981).

To widen the adaptation of pigeonpea it is necessary to identify less photosensitive and cold tolerant traits. The Genetic Resources and Pigeonpea Breeding Units at ICRISAT have conducted extensive screenings for photoinsensitivity, it is usually found that this character is inversely proportional to maturity duration but there are genotypic differences with some maturity groups. In the Indian subcontinent, there is scope for developing pigeonpea as a winter crop; for eg. in rice fallows. For this, we need to incorporate, in addition to photoinsensitivity, greater cold tolerance. Although some genotypes are better able to withstand low temperatures in northern India, systematic screening for low temperature tolerance has not been made.

Growth Analysis

As already mentioned pigeonpea not only has a wide range of growth habits but is grown in a multitude of cropping systems. Thus many different growth patterns are possible. The object of growth analysis studies was to establish growth and partitioning curves so as to quantify growth and yield formation. Fig. 1 is an example of the pattern of distribution of dry matter in stems, leaves and reproductive structures of pigeonpea grown as a sole crop at Hyderabad in peninsular India. Initial relative growth rates (RGR) seem rather low for above-ground parts of pigeonpea; viz. about 0.10 $g\ g^{-1}\ day^{-1}$ for the first 50 days of growth. This contrasts with other monsoon crops, such as jute (*Corchorus olitorius*), where initial RGR to 50 days is about 0.20 $g\ g^{-1}\ day^{-1}$ (Johansen *et al.* 1985). The dry weight of the leaves declined during the later part of the reproductive phase, owing to senescence and abscission. The growth of the stems continued during the reproductive phase in all cultivars, including the determinate cultivar, Pusa Ageti.

Comparisons of a range of determinate and indeterminate cultivars in different duration groups have shown that the morphologically determinate habit confers no advantage in yield (ICRISAT, 1979). On the other hand, the determinate types suffer heavily from pod damage by *Heliothis armigera*, the major pest on pigeonpea, when they are not heavily protected by pesticides.

Changes in leaf area index (LAI) with time closely parallel the changes in leaf dry weight. The maximum LAI of medium duration cultivars grown in the normal season at Hydrabad usually range from 3 to 6; and in the postrainy season crops, planted around October, LAI rarely exceeds 1, even with high population densities. Net assimilation rates (NAR) for the cultivars shown in Fig.1 showed a declining trend through most of the growth period. They were around 50 $g\ m^{-2}\ week^{-1}$ at the time of flowering (Sheldrake and Narayanan, 1979).

In intercropping systems in which pigeonpea is shaded by a faster growing companion crop such as sorghum, the growth rate and LAI are, not surprisingly, much lower than in comparable pigeonpea grown as a sole crop. However, after the harvest of the intercrop, the amount of light available to the plants is greatly increased; the growth rate accelerates and the plants partially compensate (Natarajan and Willey, 1980).

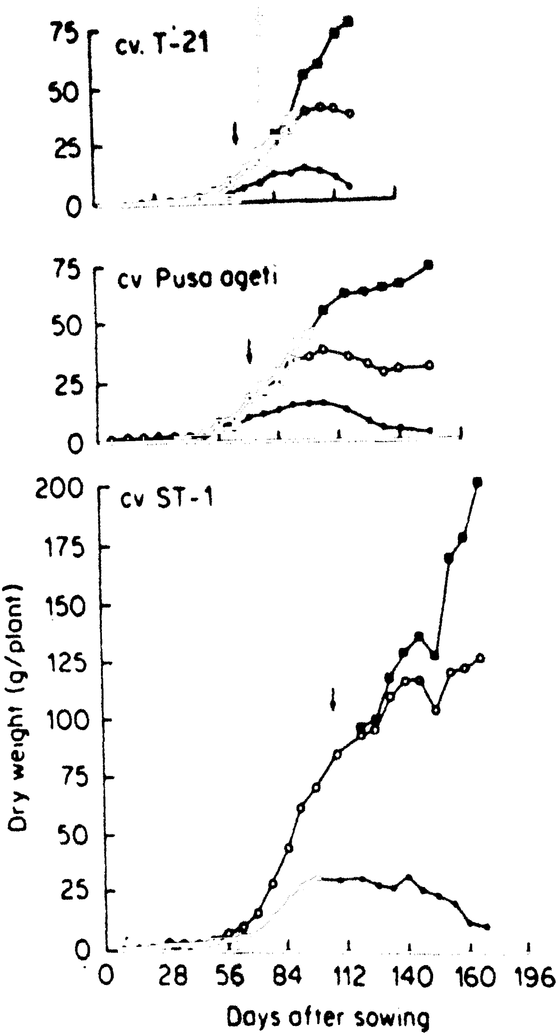

Fig.1. Accumulation and distribution of dry matter in the leaves (●-●), leaves + stems (o-o), and leaves + stems + reproductive structures (■-■) of an early indeterminate pigeonpea cultivar (T-21), a morphologically determinate cultivar (Pusa ageti) and a medium duration indeterminate cultivar (ST-1) grown on a Vertisol at Hyderabad. Arrows indicate time at which flowering began. (From Sheldrake 1984).

From the above, it is clear that there is a need to develop pigeonpea ideotypes for different environments and cropping systems. A major physiological detect of pigeonpea for sole cropping appears to be its slow early growth rate which in the environment of the peninsular India often results in inadequate biomass formation of short-duration pigeonpea. Studies have been initiated to screen for genotypes with higher initial growth rates.

Nutrient uptake

Measurements on field grown plants have shown that nitrogen, phosphorus, and potassium uptakes take place throughout the vegetative phase and continue during the reproductive phase (Sheldrake and Naryanan, 1979; Natarajan and Willey, 1980). However, throughout the growing season the percentage content of these elements in the various vegetative and reproductive organs declines (Sheldrake and Narayanan, 1979; Natarajan and Willey, 1980; Ahlawat, 1981). For example, in pigeonpea grown in the normal season at Hyderabad, the percentage of nitrogen in the leaves declined from a maximum of around 5 per cent to 1.5 per cent at the time of abscission, and of phosphorus from 0.3 per cent to less than 0.1 per cent showing that over two-thirds of the content of these elements was remobilized during the process of leaf senescence. Calculations have shown that remobilization from the leaves can account for most of the nitrogen in the seeds and for at least half the phosphorus (Sheldrake and Narayanan, 1979).

Some data for the distribution of dry matter and nutrients in the above ground parts of the plants at the time of harvest of a medium duration cultivar grown in the normal season at Hyderabad are shown in Table 1. The amount of nitrogen in the root system was estimated to be about 10 kg ha^{-1} (Sheldrake and Narayanan, 1979). When added to the 89 kg ha^{-1} in the shoot system, this gives a total uptake of about 100 kg ha^{-1}. Since the crop was grown on soil low in available nitrogen and without nitrogenous fertilizer, much of this was probably fixed in the root nodules. Over 2 t ha^{-1} or material, mostly fallen leaves, was returned to the surface of the soil, containing over 30 kg ha^{-1} nitrogen.

Table 1. Dry weight and nitrogen and phosphorus content of above ground parts of medium duration pigeonpea (cv. ICP 1) at the time of harvest. The plants were grown on a Vertisol at ICRISAT Center, Hyderabad in the normal season (sown at the end of June, harvested in mid-December).

Component	Dry matter	Phosphorus		Nitrogen	
	kg ha^{-1}	%	kg ha^{-1}	%	kg ha^{-1}
Seed	1007	0.29	2.9	3.45	34.7
Pod wall	428	0.03	0.1	0.68	2.9
Stem	2132	0.05	1.1	0.53	11.3
Attached leaves	290	0.15	0.4	2.93	8.5
Fallen material	2157	0.06	1.3	1.48	31.8
Total	6305	-	5.8	-	89.2

In further studies at ICRISAT, using a larger range of cultivars, the Microbiology group have recorded total nitrogen uptakes in a range from 69 to 134 kg ha^{-1}, and in one experiment, they estimated that 40 kg ha^{-1} of residual nitrogen was used by a subsequent cereal crop (Kumar Rao et al. 1981). Total nitrogen uptakes reported for pigeonpea crops in other parts of India range from 72 to 216 kg ha^{-1}, and phosphorus uptakes from 10 to 24 kg ha^{-1} (Ahlawat, 1981).

In an extensive series of fertilizer trials carried out at different locations in India, positive yield responses were obtained with starter doses of 20 to 25 kg ha^{-1} nitrogen, and in soils low in available phosphorus there have been significant positive responses to phosphatic fertilization (Kulkarni and Panwar, 1981). The latter result is hardly surprising; but compared with cereal crops, pigeonpea seems to be rather efficient at taking up phosphate from the soil. At ICRISAT Center, Hyderabad, it has been observed on several occasions that pigeonpeas show almost normal growth in soils in which cereal crops show striking responses to phosphate application.

Nitrogen fixation

Nodulation

Pigeonpeas are generally regarded to be well-adapted to soils of moderate to poor fertility (Ahlawat 1981). However, the nitrogen nutrition of pigeonpea crops, and particularly the role of nitrogen fixation, are poorly understood. Field surveys suggest that yield is limited by poor nodulation in farmers' fields in northern India (Khurana and Dudaja, 1981) where individual plants produced fewer than ten nodules in most soils. However, nodule weight and number per plant were not closely correlated with the effectiveness of the strain of Rhizobium in increasing seed yield (Rewari et al. 1981).

Nodulation in pigeonpeas can proceed rapidly in most soils. Thompson et al. (1981) recorded about twenty-five nodules per plant fifteen days after sowing in an Alfisol at Hyderabad. Rate of nodulation is affected by soil nitrogen concentration. Kumar Rao et al. (1981) reported that nodulation and nitrogenase activity were depressed by soil nitrogen concentrations greater than 25 ppm N (as NO_3). Quilt and Dalal (1979) found negligible nodulation in plants up to ten weeks old in soils with 50 ppm N whereas normal nodule formation occurred at soil N concentrations of around 20 ppm. Applications of nitrogen fertilizer at planting reduced nodule weight per plant by 74% at twenty days, but by sixty days no differences in nodulation were apparent (Kumar Rao et al. 1981). While early N application increased plant size, seed yield was increased in only one year out of three.

Response to inoculation

Marked increases in seed yield have been reported following inoculation with an efficient and dominant strain of Rhizobium. In trials conducted within the All-India Coordinated Pulse Improvement Project on Improvement of Pulses (Rewari et al. 1981), there was a general increase in yield in eight of the eighteen trials conducted in different climatic zones. Increases in seed yield by as much as 79% (730 kg ha^{-1}) over uninoculated controls were recorded. Other authors have recorded increases ranging from 9-45% (Dahiya et al, 1981; Khurana and Dudeja, 1981; Quilt and Dalal, 1979).

Given the diversity of pigeonpea cultivars, production systems and cultural environments (including soils), host genotype x strain of Rhizobium x location interaction effects on plant productivity would not be unexpected and have been reported (Rewari et al. 1981). The cause of these interactions was not determined since nodule collection and typing was not carried out, but they may reflect in part the competitive advantage of the inoculum strains in different soils. If this is so, then introduction of inoculants of specific strains for particular cultivars and regions may be justified. Thompson et al. (1981) considered that the inoculum must provide at least 1000 and preferably close to 10000 Rhizobia seed^{-1} if adequate opportunity for infection by an applied strain is to exist.

To determine inoculation requirement in unknown areas, it is suggested to conduct most probable number (MPN) determinations of native rhizobia and also 'need-to-inoculate' trials in the field.

Fixation of nitrogen

In general, nitrogen accumulation in the young crop is slow, and maximum nitrogen uptake does not occur until immediately before flowering. Chopra and Sinha (1981) reported that the greatest rate of nitrogen accumulation in cultivar Prabhat occurred between eight and ten weeks, and maximum crop growth rate between ten and twelve weeks. Similarly Sheldrake and Narayanan (1979) detected maximum nitrogen uptake in the cultivar ICP 1 of 1.7 kg N ha^{-1} day^{-1} between days to 60 and 90, while maximum crop growth rate occurred between 90 and 120 days. In a study of the transport of ureides (allantoin) in xylem sap, used as an indirect measure of nitrogen fixation, Kumar Rao et al. (1981) found maximum concentration occurred some two weeks before flowering in the cultivar UWI 17. Net uptake of nitrogen may continue throughout the reproductive phase, although various proportions of nitrogen for seed yield originate from retranslocation from elsewhere in the plant. Chopra and Sinha (1981) found that 68% of total N uptake was achieved before flowering. Under field conditions, nitrogen fixation may decline during the reproductive phase due to nodule degeneration, lack of soil moisture or nodule damage by the larvae of a platystomatid fly (Rivellia angulata) (Sithanantham et al. 1981).

At ICRISAT, Kumar Rao and Dart (1987) estimated nitrogen fixation by subtracting the amount of nitrogen accumulated by a 175-day sorghum crop from the total nitrogen yield of the pigeonpea. For cultivars of similar crop duration, nitrogen fixation varied from 13-55 kg N ha^{-1}. Using ^{15}N it has been reported that about 90% of total N in a medium duration pigeonpea grown at Hyderabad was derived from N_2 fixation and there was little transfer of fixed nitrogen from pigeonpea to associated cereal crop during the growth (Kumar Rao et al. 1987).

Nitrogen return to the cropping system

Approximately 35 kg N ha^{-1} were removed with each tonne of seeds harvested (Geervani, 1981). Assuming return of all non-seed materials to the soil, returns of 26-100 and 56-70 kg N ha^{-1} have been estimated (Kumar Rao et al. 1981; Sheldrake and Narayanan, 1979). The harvest index for nitrogen ranged from 21% to 52% and was greatest in the early cultivars. These values are small relative to other grain legumes (Pate and Minchin, 1980), viz. cowpeas 61%, soybeans 75%, groundnuts 80%, faba beans 76% and chickpeas 73%.

In most traditional production systems, whole plants are cut and threshed after removal from the field, the stems being used as firewood and the threshings as fodder. Sheldrake and Narayanan (1979) estimated that root systems contribute about 10 kg N ha^{-1} and fallen material 30-35 kg N ha^{-1}, making an average return of 40 kg N ha^{-1}. Similar estimates were reported by Kumar Rao et al. (1981). These values are similar to comparisons with nitrogen-fertilized maize crops following pigeonpea (Kumar Rao et al. 1983), where the residual effect of pigeonpea was also equivalent to the application of about 40 kg N ha^{-1}.

Seed yield and harvest index

Pigeonpea is a relatively low-yielding crop. In 1980 the world average yield was 684 kg ha^{-1} and the Indian average 692 kg ha^{-1} (Parpia, 1981). At ICRISAT Center, the average yields of medium- and short-duration genotypes under rainfed conditions are around 1.5 t ha^{-1} and 0.8 t ha^{-1}, respectively. The yields of short-duration genotypes in northern India are around 2 to 3 t ha^{-1}. These differences may be due to the generally warmer conditions in the pigeonpea growing regions of the North during the monsoon season. The growth of pigeonpea is greatly influenced by temperature and in controlled environment studies with mean temperatures in the range 20 to 28°C has been found to have a Q10 of about 2.5 (Sheldrake, 1984).

The highest grain yields of about 4 t ha^{-1} were reported in long-duration pigeonpea, in traditional cropping systems, in frost-free regions of north-central and north-west India (Singh and Kush, 1981). In Australia, short-duration and relatively photoinsensitive pigeonpea lines have been reported to yield as much as 4.5 t ha^{-1} under irrigated conditions (Wallis et al. 1981). At ICRISAT Center, short-duration pigeonpea in multiple harvest system has been reported to give up to 5.5 t ha^{-1} in intensive cropping systems (Chauhan et al. 1987). These results show that the yield potential of pigeonpea in intensive cropping systems is considerably higher than previously thought.

Because of the perennial nature, harvest index of pigeonpea is normally low (0.15-0.20, including fallen leaves) and strongly influenced by environmental conditions (Sheldrake and Narayanan, 1979). However, where vegetative growth is restricted, such as when pigeonpea is grown in the cool, post-monsoon season, harvest indices may reach 0.50 (Sheldrake, 1984).

Yield components

Although there are large variations among cultivars in seed size and seed number per pod, within a cultivar these are remarkably constant; pod number per unit area appears to the major determinant of yield in pigeonpea (Sheldrake, 1984). In indeterminate cultivars, seed number per pod and individual seed weight does not vary with their stage of formation (Sheldrake and Naryanan, 1979), in contrast with the pattern in annual legumes such as chickpea. Sheldrake (1979) has developed a hydrodynamical model to help explain the physiology of pod set in pigeonpea. This is based on results of flower removal and defoliation experiments (Sheldrake et al. 1979) and suggests that the pod setting is adjusted in such a way that the fewer pods are set than the plants are capable of filling. There seems to be a threshold level of assimilate supply below which podsetting does not take place. The reasons for this behaviour, and possible ways of lowering this threshold level, are not readily apparent. Perhaps a better understanding of hormonal factors affecting flower abscission and assimilate movement in pigeonpea is needed.

Pigeonpea Agronomy Research

The objective of research in pigeonpea agronomy at ICRISAT is to identify factors of the physical environment, or particular plant characters limiting higher yields of pigeonpea. Genetic or management solutions or a combination of both, are then evaluated for alleviating the constraints. A brief overview of pigeonpea research in the Pulse Agronomy Unit of the Legumes Program at ICRISAT, highlighting some of the ongoing work and possible future direction of research is given below, and we think that this is relevant to northern India or Nepal.

Response to drought

Pigeonpea is generally considered as well adapted to drought conditions although large responses to irrigation can be obtained (Rao et al. 1983). Pigeonpea sown at the beginning of the monsoon period face two types of drought stress during their life cycle. Firstly, there is the intermittant drought stress during vegetative growth in the monsoon season, which may limit early vegetative growth on lighter soils. Secondly, there is the stress induced by receding soil moisture in the post-monsoon period, as faced by chickpea.

In medium-duration pigeonpea (160-180 days), large genotypic differences in response to irrigation applied after cessation of rainy season in Sept.-Oct. have been recorded. Genotypes ICP 3233, 4865, 8340, BDN 5, and PDNA 53 performed relatively well without supplementary irrigation. We are hopeful that genetic improvement of tolerance to drought stress is possible.

In short-duration (110-140 days) pigeonpea, we know little about their moisture requirements. They can suffer from moisture deficit during the vegetative and early reproductive growth periods, particularly in central and southern India when there are gaps in the rains. Field studies initiated in 1986 rainy season on the response to moisture application using a line-source sprinkler system revealed large genotypic differences in response with genotypes such as ICPL 151, 161, 8321 being more sensitive to moisture stress and ICPL 81, 87, 8304 less sensitive.

Response to waterlogging

Even in semi-arid regions, heavy rainfall during the wet season can result in waterlogging, especially in the poorly drained soils on which pigeonpeas are often grown (Reddy and Virmani, 1981). There are cultivaral differences in waterlogging tolerance (BDN 1 tolerant and HY 3C susceptible) and response tends to vary between experiments. Therefore the screening methods need to be further standardized.

Response to salinity

Some of the regions in which pigeonpea is grown, or in which it could be grown are affected by soil salinity. Using pot trials, genotypic differences have been observed in salt tolerance; eg. pigeonpea genotypes ICPL 227 and C 11 are relatively salt tolerant while *Atylosia platycarpa* possesses high levels of salt tolerance. It would be worthwhile if a such high level of salinity tolerance in *A. platycarpa* can be incorporated into cultivated pigeonpeas.

Cropping systems improvement

Long-duration pigeonpea intercrops

Such traditional cropping systems are important in northern India where winters are too cool to allow much vegetative or reproductive growth of pigeonpea; yield formation occurs in the following spring. Pigeonpea is normally intercropped with sorghum or millet, which is harvested at the end of the rainy season leaving the pigeonpea to grow another six months for harvest in late spring. We are trying to determine the optimum canopy structure of pigeonpea for such systems by comparing genotypes with growth habits ranging from erect to spreading. Preliminary studies indicated little difference in yields of erect and spreading type pigeonpea in such a system, because of overriding effect of factors other than canopy structure eg. length of podding period under favourable conditions.

Short-duration pigeonpea rotation with winter crops

The advent of short-duration pigeonpea has made it possible to harvest pigeonpea monocrops in time to sow a winter crop usually wheat, in the northern Indian environment. This cropping system has been widely adapted over the previous decade but some problems remain. Firstly, there is considerable instability over years of days to maturity; late monsoon rains can induce flower drop and thus delay maturity. We are therefore testing a factorial combination of planting dates and pigeonpea genotypes differing in average days to maturity to develop a system to ensure that pigeonpea vacates the field by the optimum sowing time for wheat, in mid-Novemebr. Secondly, vegetative growth of short-duration pigeonpea in the northern Indian environment is prolific, with crop height often exceeding 2 m, and this complicates necessary cultural operations such as spraying of insecticide. The plant breeders have developed dwarf genotypes of short-duration pigeonpea and in the current season we are conducting sowing date x population studies, to find optimum combinations for these essentially new plant types.

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