Adaptation of Chickpea and Pigeonpea to Abiotic Stresses

International Crops Research Institute for the Semi-Arid Tropics

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Cover: Screening for adaptation to abiotic stresses: testing chickpea lines in the field under graded drought stress (bottom); and pot screening pigeonpea for waterlogging tolerance (top).

Adaptation of Chickpea and Pigeonpea to Abiotic Stresses

Proceedings of the Consultants' Workshop held at ICRISAT Center, India, 19-21 December 1984

Organized by the
International Crops Research Institute
for the Semi-Arid Tropics (ICRISAT)

ICRISAT
International Crops Research Institute for the Semi-Arid Tropics
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Drought remains an important issue in the efforts of nations to feed themselves. Its magnitude in several parts of Africa has led to acute food shortages in recent years, and this has been a matter of great concern worldwide.

Drought, however, is only one among several factors in the physical environment that can limit yields, particularly in the semi-arid tropics. Temperature, salinity, and waterlogging are all important. And these factors often interact among themselves, so that the actual problems are difficult even to diagnose, let alone resolve.

As part of an overall effort to consider how existing knowledge can be applied toward alleviating those physical limitations, and to plan future research, ICRISAT hosted a Consultants' Workshop during 19-21 December 1984 on "Adaptation of Chickpea and Pigeonpea to Abiotic Stresses." This volume brings together papers presented at the workshop, along with its recommendations.

With proper application of research, we believe that catastrophic food shortages can be minimized or averted. Events of recent years have added a sense of urgency to the task of improving the ability of crops to withstand physical stresses, particularly drought.

We hope that this volume will contribute meaningfully to such ameliorative research efforts.

L.D. Swindale
Director General, ICRISAT

Introductory Session

Chairman : L.D. Swindale
Rapporteur: N.P. Saxena

Welcome Address

L.D. Swindale[1]

On behalf of the organizers, I welcome you all to this workshop. We particularly welcome the participants from outside ICRISAT and hope they will find the venue for this meeting suitable and attractive.

This workshop, dealing with the adaptation of pulses to abiotic stresses, is an important one for ICRISAT and, I hope, also for our visitors. As most of you are fully aware, abiotic stresses on food crops are of great importance and concern in the world today. This is particularly so if many parts of Africa, where severe droughts have occurred and food supplies have suffered catastrophically. News has recently focused on Ethiopia, but I can assure you that droughts of similar magnitude have been occurring in several parts of the African continent, causing great problems for their peoples and governments and for those concerned with aiding them.

With proper application of existing research knowledge, those catastrophic situations need not have occurred. Most of you know how to deal with those problems so that at least moderate degrees of physical stress on crops can be successfully abated. Only under very severe conditions would we expect to find the types of problems that are occurring today in parts of Africa. More research is certainly needed, but we should take into account the state of the art today. Most of us understand, I think, that research is sometimes part science and part art, and thus a reference to "state of the art" is not entirely inappropriate.

I hope that in this workshop you will be able to update the state of the art concerning the tolerance of chickpea and pigeonpea to physical stresses and also suggest ways to accelerate progress. There is a sense of urgency about what you are doing and about the need to improve the ability of these crops to withstand physical stresses, particularly drought. We should use as many channels and avenues for improvement as possible, and we hope our visitors will suggest some alternative approaches to the problems we are tackling at ICRISAT. I hope you will give full attention to the activities scheduled for you and that you will profit from participating in the workshop.

It is now my pleasure to ask Dr. J.S. Kanwar, ICRISAT's Director of Research, to talk about the purposes of the workshop. Dr. Y.L. Nene, Leader of the Pulses Improvement Program at ICRISAT, will then review pulses research at ICRISAT.

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[1] Director General, ICRISAT.

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Keynote Address—Objectives and Relevance of the Workshop

J.S. Kanwar[1]

Let me extend a warm welcome to you for participating in this workshop. In the past, greater importance has been given to biotic stresses such as diseases and pests, where greater possibilities exist of incorporating desirable traits of resistance or tolerance. People have been talking about and measuring physical stresses, but few achievements have been reported in building tolerance to them. In this workshop, which is rather a discussants' meeting, we wish the group to critically review the state of the art and suggest a strategy for removing or mitigating abiotic constraints to production.

Two important pulses of the semi-arid tropics (SAT) are chickpea and pigeonpea; chickpea is grown on 10.5 million ha, and pigeonpea on about 3 million ha. The rapid decline in per capita availability of these pulses in developing countries of the Indian subcontinent (India, Pakistan, Nepal, Bangladesh, and adjoining countries) is causing a great nutritional imbalance, particularly for the poor who depend solely on pulses for supplementing cereal proteins.

The growing awareness of this situation and research over the past decade have resulted in perceptible gains in production of pulses, but yields have not really increased. As pulses are being pushed to more marginal lands and unfavorable environments, the improvement in their yield potential is not realized.

It is the extension of irrigation and breakthroughs in wheat and rice production technology that are pushing pulse crops to more marginal lands and less favorable environments. To define this situation, attention should be directed to abiotic factors in pulses, including:

1. nutrient deficiency stress (e.g., N, P, K, S, Fe, Zn, Mo, etc.);
2. nutrient toxicity stress (e.g., salinity, Al, Mn, and other trace elements);
3. soil reaction stress (e.g., acidity and alkalinity);
4. moisture deficiency stress;
5. moisture excess or waterlogging stress;
6. high or low temperature stress; and
7. soil physical stress (e.g., poor soil structure, lack of aeration, etc.).

All these are serious abiotic constraints to production of pulses, affecting both crop stand and yield.

Some of these constraints can be removed through inputs such as irrigation and fertilizers, but unless the genotypes are capable of giving high yields, comparable with cereals, the use of inputs will not become attractive. Moreover, the use of fertilizer, which has revolutionized the production of cereals through the introduction of fertilizer-responsive varieties, seems to be still remote for pulses. Scientists continue to argue whether pulses are really responsive to fertilizers, because the experience on farmers' fields and at research stations is at variance. The conflict cannot be resolved without critical studies, especially in pigeonpea. Some of the research needs can be summarized as follows.

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[1] Director of Research (now Deputy Director General), ICRISAT.

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Both chickpea and pigeonpea are grown under rainfed conditions, with stress from receding moisture in chickpea and long-duration pigeonpea and from intermittent moisture in short- and medium-duration pigeonpea. Both crops are subject to moisture deficits at the critical stages of pod filling and maturity. In addition, pigeonpea suffers from waterlogging, lack of aeration, and poor drainage in some soils. Salinity and alkalinity affect both crops, reducing plant stand and yield. It has been observed that if the salts are sulfates, chickpea's tolerance limit is far higher than if they are chlorides. There is evidence that sulfur deficiency can affect yield in both crops. Iron chlorosis seems to be common in chickpea growing on calcareous soils. There is also evidence of significant genetic differences in sensitivity to zinc and iron deficiency in chickpea; these differences can be exploited by the breeders.

The beneficial residual effect of legumes in supplying fixed nitrogen to subsequent crops is well known. What is not clearly understood is whether there are any significant genetic differences in the nitrogen-fixing capability among different genotypes of chickpea and pigeonpea. The role of different environmental factors in controlling nitrogen-fixation in these legumes also awaits definition.

There is very little reported work on frost or cold tolerance in either chickpea or long-duration pigeonpea. Last year, I observed the large-scale devastating effect of frost on long-duration pigeonpea in Uttar Pradesh and Madhya Pradesh. I also noticed some lines in ICRISAT experimental plots which had not suffered much; whether this survival was because of tolerance or quick regenerative ability needs to be determined.

The possibility of multiple harvests and high yield potential in pigeonpea has been reported, but whether this phenomenon can be exploited on a commercial scale through manipulation of environments remains to be seen.

Root extension, root proliferation, and moisture extraction patterns of both crops need to be studied as they are related to general crop productivity and drought tolerance. The suitability of the line-source irrigation technique to screen for drought tolerance in both pulse crops seems to be questionable. Other reliable methods need to be developed to screen for receding soil moisture.

Manipulation of physical soil environments to improve crop stand and yield is another important aspect that needs investigation.

I believe these various aspects of abiotic factors deserve consideration. The international workshops on grain legumes in 1975, chickpea in 1979, and pigeonpea in 1980 all drew attention to these problems in one way or another, but the situation has not changed much over the years and we need to have a fresh look.

I feel there is thus an urgent need to critically examine available research on physical constraints to pulse production and to fix priorities of research to achieve short-term and long-term objectives. It is not enough that we lament the inadequacy of knowledge on the subject. We should develop mechanisms for achieving the set goals through collaborative scientific efforts and by pooling material resources.

Both basic and strategic research should lead to results of practical significance. I am sure this group of scientists will identify concepts and priorities that need investigation. In addition, I hope you will also develop work plans and mechanisms for cooperative research.

I wish you success in your deliberations.

Overview of Pulses Research at ICRISAT

Y.L. Nene[1]

Abstract

This paper provides a brief overview of ICRISATs interdisciplinary research on chickpea and pigeonpea. Global area under the two crops is mentioned; chief constraints in their production and priorities for research emerging therefrom are outlined; and ICRISAT's research progress in developing screening capabilities against biotic and abiotic stresses is summarized. Breeding efforts that follow the screening are outlined, and successes in release of improved materials to farmers mentioned.

The Pulses Improvement Program at ICRISAT is concerned with research on the two important pulse crops of the semi-arid tropics (SAT)—pigeonpea and chickpea. The research is interdisciplinary, with breeders, pathologists, entomologists, crop physiologists, and microbiologists working together on the common objective of improving stability and yield of the two crops.

The global area under chickpea cultivation at present is over 10 million ha, and chickpea is the third most important grain legume in the world, after beans and peas. Dr. Kanwar has already pointed out that presently chickpea yields are quite low—around 700 kg ha^{-1}. A little over 3 million ha are under pigeonpea cultivation, for which also present yield levels are quite low, around 600 kg ha^{-1}. Yield potential of both crops is high, however: around 4000 kg ha^{-1} have often been realized at experiment stations. The harvest index is markedly different in the two crops; in chickpea it may be as high as 60%, but in pigeonpea it ranges between 15 and 30%. Growth duration of the two crops depends upon location, season, and cultivar; crop duration is generally 4-6 months in chickpea and 4-10 months in pigeonpea.

Most of our research is carried out here at ICRISAT Center. In addition, we have facilities, made available through cooperative agreements, to work at other agricultural research centers and universities in India. At Hisar, we carry out experiments on short-duration pigeonpea and long-duration chickpea; the results of this work are relevant and applicable to northern Indian environments, as well as to Pakistan and Nepal. At Gwalior, our research is primarily on long-duration pigeonpea. We also have an off-season nursery at Tapperwaripora in Kashmir for multiplying chickpea seed, thus enabling us to rapidly advance generations. We have similar cooperative agreements to screen for tolerance to certain diseases, such as ascochyta blight and botrytis gray mold in chickpea. These diseases do not occur here at Patancheru, whereas they are endemic in those areas, thus making them excellent sites for our cooperative research.

If one analyzes the problems that confront increasing production of pulses, the following points emerge:

1. Chickpea and pigeonpea are considered low-priority crops by farmers because remunerative harvests are uncertain.
2. These crops are grown in subsistance rather than commercial farming systems.
3. Their response to fertilizers and irrigation is gen-

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[1] Program Leader, Pulses Improvement Program (now Program Director, Legumes), ICRISAT.

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erally not remunerative.

4. These crops are relatively more susceptible to pests and diseases.
5. Growth duration of 150 days in chickpea and more than 180 days in pigeonpea is excessively long.
6. Traditional pigeonpea cultivars are too tall, and thus difficult to manage. Chickpea cultivars are short and bushy and lodge quite often; their proximity to the ground encourages disease problems.
7. Nodulation in farmers' fields is generally poor for these two crops.

I wish to point out that ICRISATand the Indian national programs have directed efforts toward solving the above problems and that we have found satisfactory solutions in many cases.

Chickpea

Chickpea is a self-pollinated annual crop. It is adapted to grow without rainfall during the growth period, either on stored receding soil moisture or with irrigation. Chickpeas are of two types—kabuli and desi. The seeds of kabulis are light colored and have a smooth surface, whereas seeds of desis are yellow to black with a rough surface. Flower color also differs: kabuli types produce white flowers and desi types produce colored flowers. Chickpea is grown as a summer crop in the Middle East, around the Mediterranean, and in the Americas; it is grown as a winter crop in more tropical climates. The relative importance of chickpea in different geographical areas is shown in Figure 1. It is apparent that the Indian subcontinent and North Africa are areas with a large proportion of chickpea in relation to other cultivated crops. However, chickpea remains an important crop in many other countries.

In chickpea research our objectives are to develop genotypes with characteristics that would contribute to higher and more stable yields of acceptable grain type under a range of cropping situations. We are breeding short-duration desi types for southern India, and short-duration kabuli types for Southeast Asia and North Africa. Work on kabuli types in particular is being done in cooperation with the International Center for Agricultural Research in Dry Areas (ICARDA), based at Aleppo, Syria. Under a joint agreement, ICRISAT has placed two scientists at ICARDA, from where they can properly serve regions of the world where kabuli chickpea is grown more widely. We are also breeding long-duration desi and kabuli types for northern India and Nepal, and desi types for Pakistan, Burma, Iran, and Ethiopia.

Our achievement so far—in terms of our capability to screen germplasm and breeding material for various stress factors—is shown in Table 1. While we are generally satisfied with our screening capability for tolerance to diseases and pests, we still need to improve screening for tolerance to drought, salinity, and other abiotic factors. The 0.5 on a 1-point scale means we have reached a level where we can start the screening process. However, we still need to improve the techniques until we reach a rating of 1.0, at which stage we can consider it an excellent technique. A rating below 0.5 indicates we have not yet reached the screening stage.

Disease resistance is a very important consideration in our plant improvement efforts. Our breeders realize the imperative need to incorporate resistance to various diseases in all breeding material. Whenever they feel they have materials ready for testing in multilocational trials, we would already have gathered enough information on many of the factors mentioned in Table 1. Once the material is identified as elite, we try to fill in the gaps in our knowledge and collect information on all the aspects mentioned in Table I, as well as on certain aspects not listed there. We collect information on about 22 different traits so that, if a particular material is found useful in any national program, we would have almost complete information related to that line. By the time a genotype is ready for multiplication, its strong and weak points are thus well documented. Some of the information we already have follows.

Heliothis is a very serious pest of chickpea as well as pigeonpea. We have identified chickpea genotypes that are tolerant of this pest.

Plant stands are often very poor in farmers' fields.

Table 1. Screening capabilities for biotic and abiotic stresses in chickpea.

Trait	Score[1]	Trait	Score
Wilt	1.0	Leaf miner	0.6
Ascochyta blight	0.9	Salinity	0.6
Dry root rot	0.9	Stunt	0.6
Heliothis	0.8	Drought	0.5
Black root rot	0.7	Grain quality	0.5
Botrytis gray mold	0.7		

1. 1.0 = excellent screening capability; 0.5 = screening may begin; and 0.0 = no capability for screening.

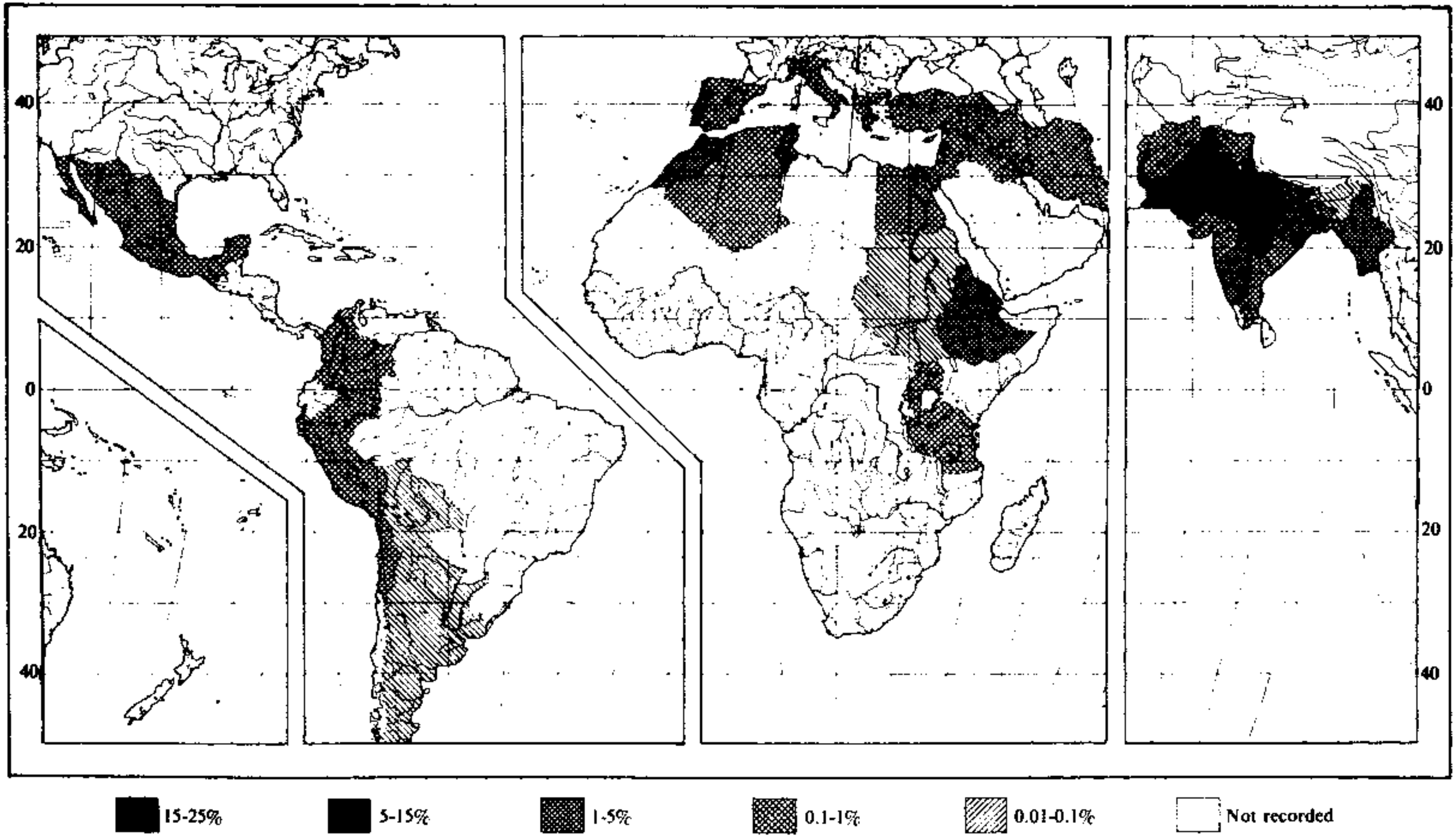

Figure 1. Chickpea-producing regions in the world and their chickpea area as a percentage of total arable area.

One major reason for this is low moisture in the seedbed at the time of sowing. Our physiologists have developed a field method and a laboratory technique that enable detection of genotypic differences in germination and emergence at suboptimal soil moisture levels. These results are promising and they should help ensure better plant stands.

Work has been done in nutrient stress as well. Genotypic differences in the efficiency of iron utilization have been identified. We have demonstrated that it is possible to ameliorate iron deficiency through sprays of iron sulfate. We also have attempted to understand the response to phosphorus in both crops.

Chickpea grows excessively vegetative either if there is excessive rainfall during the season or if, in irrigated areas, enthusiastic farmers overirrigate the crop. The excessive vegetative growth invites many problems, such as lodging and increased incidence of diseases caused by *Botrytis* and *Ascochyta.* Germplasm is being screened to identify genotypes that will not produce excessive vegetative growth even where moisture is above optimum. They will not then form a very thick canopy and will still allow the light to penetrate, thereby overcoming many of the problems mentioned earlier. Our research on responses to fertilizer and to irrigation will be covered in greater detail later in this workshop.

Our microbiologists have generated very useful information. They have found that chickpea rhizobia exist at soil depths greater than 1 m. Seasonal variations in rhizobial numbers, particularly in the top 5 cm, have been observed. Soil temperatures above 30°C have been found to adversely affect nitrogen fixation. It is interesting that chickpea rhizobia can survive in the soil for at least 5 years and can multiply in the rhizosphere of the other four mandate crops of ICRISAT. Between 87 and 90% of the plants' nitrogen seems to come from biological nitrogen fixation. So far, two strains of rhizobia have shown promise for efficient N_2 fixation. One of these, IC-76, has been recommended by the All India Coordinated Pulses Improvement Project (AICPIP) as a strain to be used for inoculating chickpea seeds. IC-26, the other strain isolated at ICRISAT from saline soil, has been found useful at ICARDA. Trials in Gujarat state of India indicated that good responses can be obtained to *Rhizobium* inoculation under field conditions.

One of the first breeding materials from ICRISAT was found to do well in Gujarat, and it is now released as a cultivar named ICCV I (ICCC4). Some of the other lines are in the process of being approved for release. ICCC 37, which has done very well in peninsular India is one such line. ICCV 6 (ICCC 32), another cultivar identified for release by AICPIP, is of great interest because it is a kabuli type with wilt resistance, a combination that did not exist earlier in the chickpea germplasm collection at ICRISAT. In addition, there are several near releases or materials released in different countries, such as Australia, Ethiopia, Bangladesh, Nepal, and through our cooperative work with ICARDA in West Asia and the Mediterranean region. Some material is now being found promising in North Africa. One of the first lines released to farmers for winter planting in Syria is ILC 482, a product of our cooperative efforts with ICARDA.

In our germplasm collection we have several double-podded genotypes that bear two pods in the axil of a leaf instead of one as in conventional types. It has been found that the double-podded character confers a yield advantage of around 11% in peninsular Indian conditions. Unfortunately all the double-podded genotypes in our germplasm collection were extremely susceptible to wilt. Through breeders' efforts, double-podded genotypes were developed that are wilt resistant and such material has been found to be quite promising.

Chickpea genotypes differ in their growth habits. Breeders at ICRISAT have been concentrating more on the development of mid-tall types. We believe that mid-tall types hold a better promise for higher yields than the tall and dwarf types. In addition, we find lines that consistently show two, three, and even up to six seeds per pod. This has opened the possibility of breeding for multiseeded characters.

Pigeonpea

Pigeonpea is a partially cross-pollinated crop. It is perennial in habit but is cultivated as an annual. It is quite tall, except for dwarf genotypes that have been identified at ICRISAT. Pigeonpea grows well during the rainy season but yields are optimum if flowering and podding occur after rainfall ceases. It grows very slowly during the vegetative stage in the first 45 days after sowing. Maximum crop growth occurs between 45 days and the beginning of flowering.

There are some clear gaps in our screening capability in pigeonpea (Table 2). We are not yet ready to screen for tolerance against some diseases and pests. In the near future we hope to improve our capabilities to screen for yellow mosaic disease and tolerance

Table 2. Screening capabilities for biotic and abiotic stresses in pigeonpea.

Trait	Score[1]	Trait	Score
Phytophthora blight	1.0	Grain quality	0.5
Sterility mosaic	1.0	Drought	0.5
Wilt	0.9	Bacterial blight	0.4
Alternaria blight	0.8	Yellow mosaic	0.3
Heliothis	0.7	Cyst nematode	0.3
Pod fly	0.7	Cercospora blight	0.0
Waterlogging	0.7	Witches' broom	0.0
Salinity	0.6		

1. 1.0 = excellent screening capability; 0.5 = screening may begin; and 0.0 = no capability for screening.

to nematodes. At present we have no capability to screen for two diseases; witches' broom does not occur in India, and cercospora blight is a disease of minor importance to the crop in this country. Witches' broom is a very severe disease in Central America and cercospora blight is quite important in Kenya and other eastern African countries. It is necessary to screen for these diseases in the regions where they are prevalent. The Program Committee of our Governing Board has now recommended that we work on witches' broom.

We conducted extensive surveys in India and eastern Africa on the occurrence and spread of wilt and sterility mosaic diseases of pigeonpea. We found that pigeonpea wilt is a problem in India as well as eastern Afica, but sterility mosaic is more or less restricted to the Indian subcontinent. These two diseases together cause losses of about US $113 million per year in India alone, and wilt causes losses of around US $5 million in eastern Africa. This amply demonstrates the attention and priority that these two diseases need. In India, very high incidence of wilt disease is reported in the states of Maharashtra, Bihar, and Uttar Pradesh. Sterility mosaic is important in several states, such as Tamil Nadu, Gujarat, Uttar Pradesh, and Bihar. Such surveys have helped us decide our research priorities for different regions in India in terms of resistance to diseases. In experiments on the effect of cultural practices on disease occurrence, pathologists and agronomists have found that intercropping pigeonpea with sorghum reduces wilt incidence in the first year of cultivation. The experiment was laid out in a wilt-sick plot. Factors that lead to reduction of wilt incidence in such an intercropping situation have not been isolated.

We have realized the increasing importance of nematodes. In one of the ICRISAT fields where sorghum and pigeonpea were intercropped for four consecutive years, we had the advantage of wilt reduction due to intercropping but a buildup in the population of lance nematodes. This nematode not only infests sorghum but also attacks pigeonpea. In an intercropping system where both the hosts are present together, this nematode finds a favorable environment in which to build its population.

Heliothis in pigeonpea is more regularly devastating than in chickpea and hence, we have devoted considerable attention to work on this pest. It causes an annual loss of US $200 million in India alone. To study the ecology of *Heliothis* in a region, we have established a network of pheromone traps. This work is being carried out in cooperation with the British Overseas Development Administration. Another serious pest of pigeonpea is the pod fly, which can devastate the crop, particularly in northern Indian environments.

We feel that ICRISAT can justifiably take credit for demonstrating the economic feasibility of cultivating postrainy-season pigeonpea. The idea was not new, but we did demonstrate its potential. Pigeonpea is grown in the postrainy season in parts of India such as Gujarat, but the system has great potential in many other areas. Subsequent to our work, the state of Bihar in northern India undertook this activity on a large scale. Postrainy-season pigeonpea has certain advantages. For example, the unmanageable height of the crop is considerably reduced, which permits easier plant protection. Also, yields very close to normal can be harvested in a shorter season.

Physiologists have been screening for tolerance of waterlogging problems, and some promising lines have been identified. ICP 1-6 is a line tolerant of waterlogging and of two major diseases, wilt and sterility mosaic.

Microbiologists have made important contributions to pigeonpea *Rhizobium* research. We now have a collection of 500 isolates. One of the strains has been recommended for use in India. In the case of pigeonpea, about 70 kg nitrogen ha^{-1} per season can be fixed by the symbiosis until the mid-pod-fill stage. This is around 88% of the total nitrogen content of the plant at that stage of growth. The residual effect on a following cereal crop can be as much as 40 kg nitrogen ha^{-1}. We have been promptly providing cultures to our cooperators on request.

The objectives in genetic improvement mentioned for chickpea apply also for pigeonpea. Some of the cultivars bred at ICRISAT have now been released[1]. Cultivar ICPL 92 was released for cultivation in Himachal Pradesh; ICPL 87, a short-duration type particularly suitable for multiple harvests, has also been released in peninsular India and in the state of Maharashtra in central India. One of our short-duration hybrids, ICPH 8, is also in a prerelease stage in minikit trials conducted in India. A cultivar, Hunt, has been released in Australia, and six more lines are in the prerelease seed increase stage there; this is a result of our cooperative work with the University of Queensland.

Vegetable pigeonpea types are important in Central America as well as in western and eastern Africa, where green peas are consumed as soups, etc. In Puerto Rico, vegetable types, generally large podded with large, sweet-tasting green seeds are preferred. Canned pigeonpeas are marketed in certain parts of the world. We have made considerable progress in developing vegetable types of pigeonpea and we do see a potential for them in some other parts of India.

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[1] The status, as regards release, of cultivars mentioned here has been updated.

Climatic Stress

Chairman : M.C. Saxena
Rapporteur: Y.S. Chauhan

Agroclimatic Environment of Chickpea and Pigeonpea

A.K.S. Huda[1] and S.M. Virmani[1]

Abstract

Chickpea and pigeonpea are grown in a wide range of agroclimatic environments. Chickpea is produced in 37 countries, and pigeonpea in 14. India accounts for 74% of total world chickpea production (6.2 million t) and 90% of the world pigeonpea production (1.2 million t). Chickpea is usually grown after the rainy season on stored soil water—during winter in the tropics and in the spring in the temperate and Mediterranean regions. Pigeonpea is usually sown at the beginning of the rainy season, as either a mixed crop or an intercrop.

To verify the performance of promising genotypes and recommended management practices, identification of a few benchmark locations is useful. Meteorological data for four contrasting chickpea-growing locations-- Hisar and Hyderabad in India, Aleppo in Syria, and Khartoum in Sudan—are given.

In India, pigeonpea-growing areas are usually located in regions with a 600-1400 mm annual rainfall and a growing period of 90-180 days. Chickpea is usually grown where mean daily maximum temperatures are 22.5-30°C and mean daily minimum temperatures 7.5-13°C during January, when flowering begins. The soils on which the two crops are grown are predominantly Alfisols, Entisols, Inceptisols, and Vertisols.

Quantitative information on the effect of environmental factors on growth and development of these crops is useful in building models for simulating yields. Using historical weather data, cumulative probabilities of simulated available soil water at sowing were computed for ICRISAT Center (Patancheru) and Hisar. At Patancheru, in a medium-deep Vertisol having 150 mm water-storage capacity, the simulated available soil water in 70% of the years studied was 120 mm under rainy-season fallow and 80 mm under rainy-season sorghum. At Hisar, the simulated available soil water after rainy season fallow in 70% of the years was more than 120 mm in soils with 150 mm water-storage capacity. Using the water use and yield relationship, cumulative probabilities of chickpea yields and phosphorus requirements were computed for both ICRISAT Center and Hisar. Although simulated yields were higher than farmers' yields, the water use and yield relationships can be used to compute the probabilities of potential yield at various locations. In some instances, simulated yields were lower than actual yields on experimental fields, and the reasons for this are explored. The delineation of the isoc limes of pigeonpea-growing areas in West Africa is also reported.

Introduction

Chickpea and pigeonpea are grown in a wide range of agroclimatic environments (Sinha 1977), and their yield potential exceeds 4 t ha^{-1} (Nene 1987). However, the yields achieved by farmers are quite low and variable. For example, in India, average yields of chickpea obtained by farmers are often only about 25% or less than can be achieved under nonirrigated conditions at experiment stations within the

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[1] Resource Management Program, ICRISAT.

Submitted as CP 382 by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Adaptation of chickpea and pigeonpea to abiotic stresses. Proceedings of the Consultants' Workshop, 19-21 December 1984, ICRISAT Center, India. Patancheru, A.P. 502324, India: ICRISAT.

same region with similar cultivars (Sheldrake and Saxena 1979). The reasons for such low yields are:

- Poor plant stand from failure of many seeds to germinate and of seedlings to become established because soil moisture is inadequate in the seed zone.
- Drought in the growing season, particularly at the flowering and pod-filling stages.
- Biotic constraints.

To develop suitable agronomic practices and to select genotypes that can cope with existing situations, it is necessary to know the range of the agroclimatic environments in which these crops are grown. Promising genotypes and recommended improved agronomic practices can be verified at a few benchmark locations representing the environment range.

Thus, the objectives of this presentation are:

1. To describe the agroclimatic environment of areas growing chickpea and pigeonpea, with emphasis on a few contrasting environments.
2. To review the available information on the effect of water, temperature, and solar radiation on the growth and yield of chickpea.
3. To discuss cumulative probabilities of simulated chickpea yield using the relationship between water use and chickpea yields.

Chickpea

World chickpea production data (FAO 1982) indicate 37 chickpea-growing countries. Total chickpea production in the world for 1982 was 6.2 million t. The chickpea-growing countries are grouped into four categories:

- India, which produced 74% of the world production.
- Pakistan, Turkey, and Mexico; production of individual countries ranged between 2.6 and 5.0% of world production, and together these countries contributed 13% of the world production.
- Burma, Ethiopia, and Syria, which contributed 1.0-2.5% individually and together contributed 6% of the total production.
- Other countries, in which individual production was below 1.0% and which together contributed 7% of the total production.

Chickpea is usually grown after the rainy season on stored soil moisture—during winter in the tropics and in the spring in temperate and Mediterranean regions. Recently chickpea has been grown in the temperate and Mediterranean regions as a winter crop when rainfall is well distributed during the growing period (Saxena 1984). The major part of West Asia and North Africa is characterized by a Mediterranean type of climate with large variations stemming from proximity to the sea, latitude, and altitude. In West Asia and North Africa, chickpea is grown mostly in areas where winter precipitation is more than 400 mm (Saxena 1987). In areas with less precipitation, but with a thermal regime permitting an adequately long growing period for economic yields, the crop is grown with irrigation (supplementary or total). The Nile valley of Egypt and Sudan is a good example. In areas receiving adequate winter rain, however, the crop is sown at the end of the rainy period (Saxena 1987).

Precipitation and evapotranspiration, maximum and minimum temperatures, and photoperiod for four contrasting environments representing the environmental range in which chickpea is grown were presented in detail by Saxena (1984). These four locations are Hisar (29°10'N) and Hyderabad (17°32'N) in India, Aleppo (36° 11'N) in Syria, and Khartoum (15°36'N) in Sudan.

At Hisar, where the maximum temperature declines from 35° to 20°C, and the minimum from 17° to 5°C, between sowing in October and flowering in January, pod set begins when minimum temperatures rise above 8°C in February. The rapid rise in maximum/minimum temperatures (from 25/8° to 37/20°C) and in evaporation (from 1-2 mm day^{-1} in December and January to 4 5 mm day^{-1} in late March and early April) hastens senescence and forces maturity. Growth duration is long, usually from 150 to 160 days. Daylength decreases from 11 h 16 min to 10 h 10 min between sowing and flowering, and increases to 12 h 44 min at maturity. On average, 370 mm of rainfall is received before sowing and 80-90 mm during crop growth.

At Hyderabad, the crop is sown at about the same time as at Hisar, but seasonal variations in mean maximum and minimum temperatures and in daylength are smaller than those at Hisar. The maximum temperature declines from 30° to 28° C and minimum from 20° to 13°C. Maximum/minimum temperatures and evaporation increase in late January and, at maturity, maximum/ minimum temperatures are around 32/16°C. The growth duration is short, usually about 100 days. Daylength decreases from 11 h 34 min at sowing to 11 h 09 min at flowering, and then increases to 11 h 24 min at maturity. On average, 600 mm of rainfall is received before sowing, and another 40-100 mm during crop growth.

The climate for spring sowing at Aleppo resembles that of Hyderabad in many respects. Between sowing in February March and harvest in June-July, maximum temperature increases from 17° to 36°C, minimum temperature from 5° to 18°C, and daylength from 11 h 0 min to 14 h 33 min. About 300 mm of rainfall is received before sowing, and another 25 mm during crop growth. In winter sowings (November-December), rainfall is well distributed during the growing period, and minimum temperature ranges between 1° and 4°C from December to March. Daylength increases from 10 h 33 min at sowing in November December to 14 h 17 man at harvest in May-June. Growth duration is long and comparable to that at Hisar.

Climate during crop growth between October and April is less favorable at Khartoum than at Hyderabad. In Khartoum, the crop is grown with irrigation and receives practically no rainfall. Maximum/minimum temperatures are 36/20°C at sowing in November, but drop to 30-33/14 16°Cat flowering and then rise again.

Since 74% of the world chickpea production comes from India, we have studied the distribution, area, production, and agroclimate of the chickpea-growing environment in India (Fig.1). The states of Madhya Pradesh, Rajasthan, and Uttar Pradesh contributed 70% of the chickpea production in India (Bose 1981). Easter and Abel (1973) demarcated the chickpea-growing regions into "core" and "satellite." A core region was one that had at least 5% of the total cropped area under chickpea and contributed at least 1% to total national production. A satellite region was one that had less than 5% but at least 2% of gross cropped area under chickpea and produced at least 0.5% of the national total.

To clarify this picture, the air temperature isotherms for October, January, and April were superimposed on the maps of core and satellite chickpea-growing regions in India (Figs. 2-4). In October, when chickpea is usually sown, the mean daily maximum temperature ranges between 32.5° and 35.0°C, while the mean daily minimum temperature ranges between 20.0° and 22.5°C. In January, when flowering usually begins, the mean daily minimum temperature ranges from as low as 7.5° to 15.0°C; the mean daily maximum temperature ranges between 22.5° and 30.0°C. As pod filling begins, the temperature starts rising and, by the time chickpea is harvested, the air temperatures rise very high. For example, in April, the mean daily minimum temperature ranges between 20.0° and 25.0°C, and the mean daily maximum temperature ranges between 37.5° and 40.0° C.

Similarly, the benchmark soils map of India (Murthy et al. 1982) was superimposed on the map of core and satellite chickpea-growing regions of India (Fig. 5). The soils are Alfisols, Inceptisols, Entisols, and Vertisols.

Alfisols are usually neutral to slightly acidic in reaction (pH 6.5-7.0), are relatively shallow (<1 m deep), have less clay content, are usually sandy loam in texture, and can retain less than 100 mm available water. Entisols are deep loams, slightly alkaline (pH 7.5-8.5), with about 150-200 mm available water-storage capacity in about 2 m soil depth. Inceptisols are mineral soils, more highly developed than Entisols, with a clay content in the surface soil ranging from 30 to 50%, and a pH ranging from 7.5 to 8.0; these soils are usually less than 1 m deep, and the available water-holding capacity is less than 150 mm. Vertisols are characterized by 40-60% clay in the surface soil horizons, with a pH of about 8.0, and they can store between 150 and 300 mm available water in the 1.5-2 m soil depth.

Effect of Environmental Factors on Chickpea Yield

Seed yield in grain legumes depends upon both vegetative and reproductive components, which are markedly affected by environmental factors (Summerfield et al. 1980, 1987). In a study on photothermal effects on flowering in chickpea, we pooled the phenology data (n = 7) for two chickpea cultivars, Annigeri and K 850, from Hisarand ICRISAT Center, Patancheru, to calculate the growing degree days (GDD) (data supplied by N.P. Saxena, ICRISAT). In the absence of defined base temperatures for different growth stages, such as sowing to 50% flowering, 50% flowering to pod initiation, and pod initiation to physiological maturity, we used 6, 8, and 10°C as base temperatures. The 8°C base temperature gave the lowest coefficient of variation from sowing to 50% flowering in both cultivars (18% in Annigeri and 16% in K 850), and the mean GDD values were 540 for Annigeri and 675 for K 850. The base temperature of 6°C gave the lowest coefficient of variation (27%) from pod initiation to physiologi-

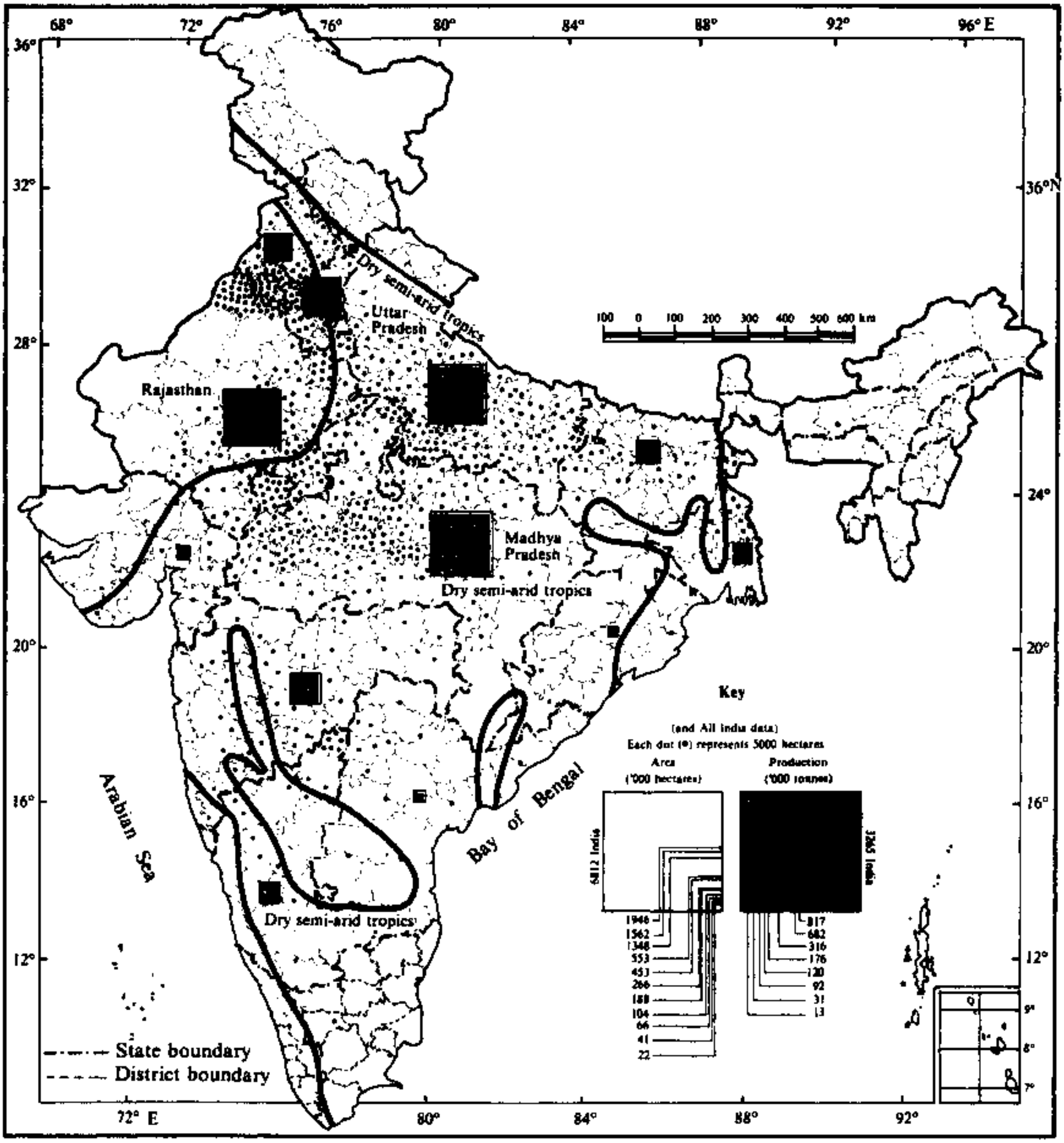


Figure 1. Distribution, area, and production of chickpea in India. (Data are given by state and relate to 1979/80).

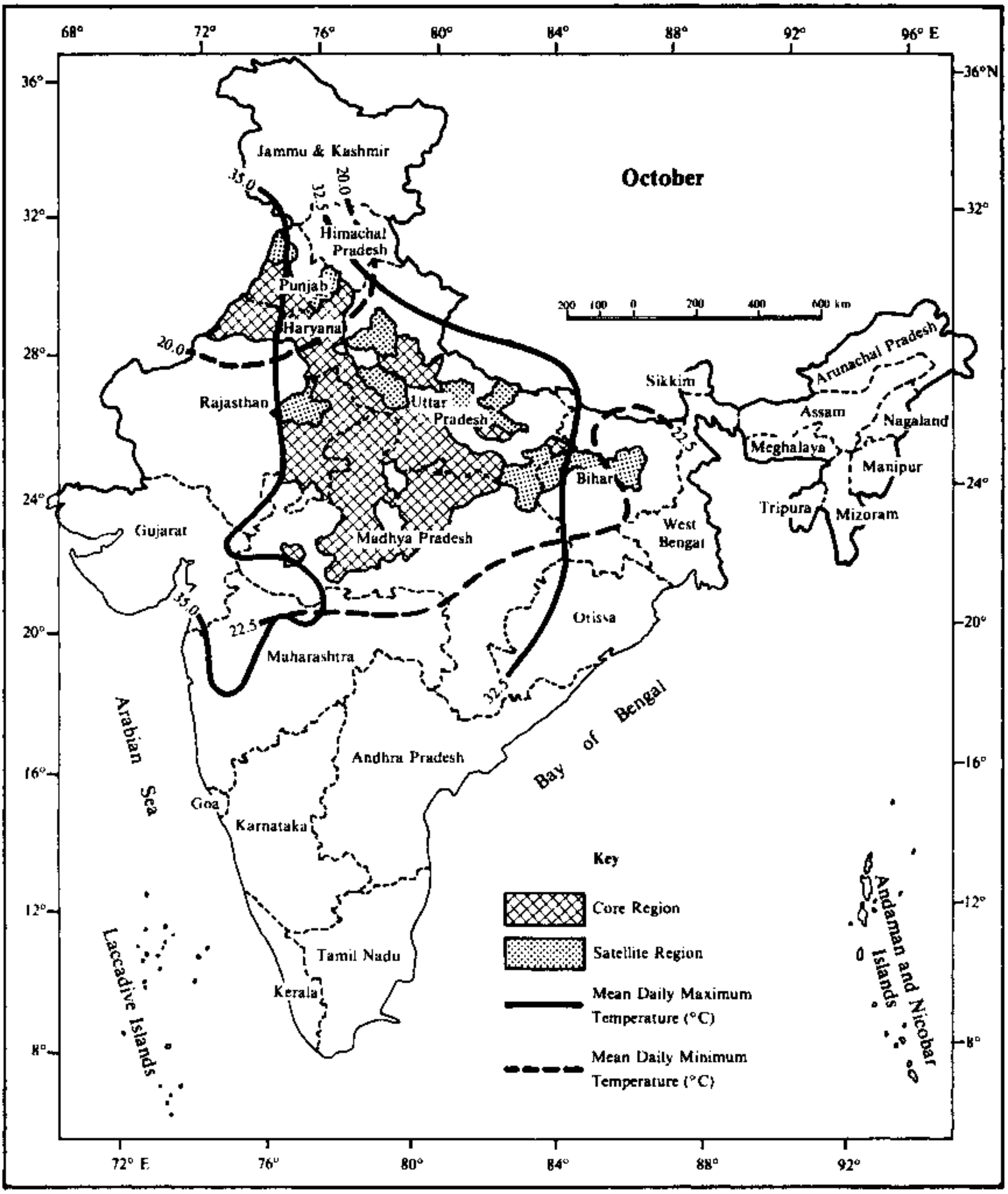


Figure 2. Mean daily maximum and minimum air temperature (° C) for October in chickpea-growing regions of India.

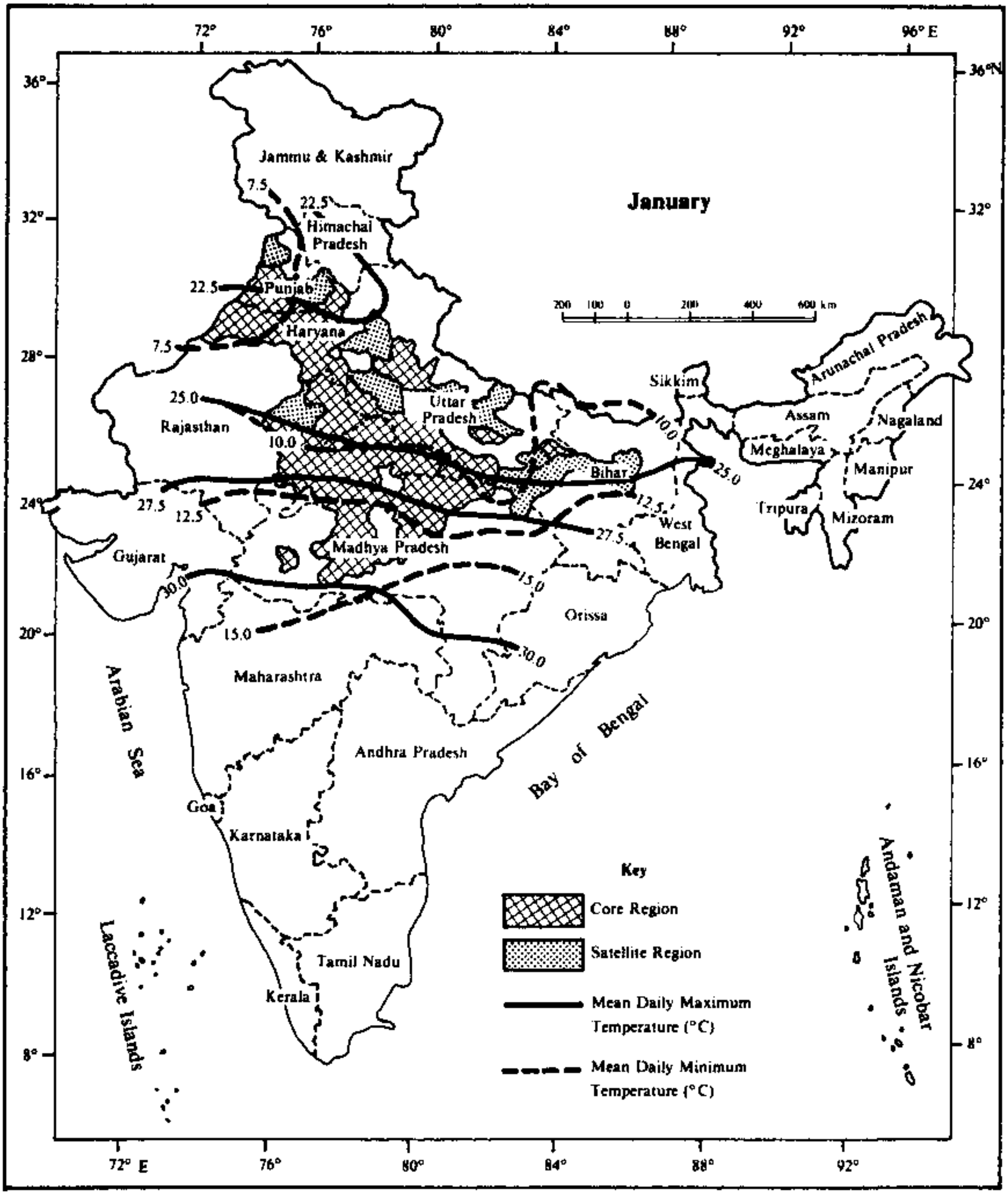


Figure 3. Mean daily maximum and minimum air temperature (° C) for January in chickpea-growing regions of India.

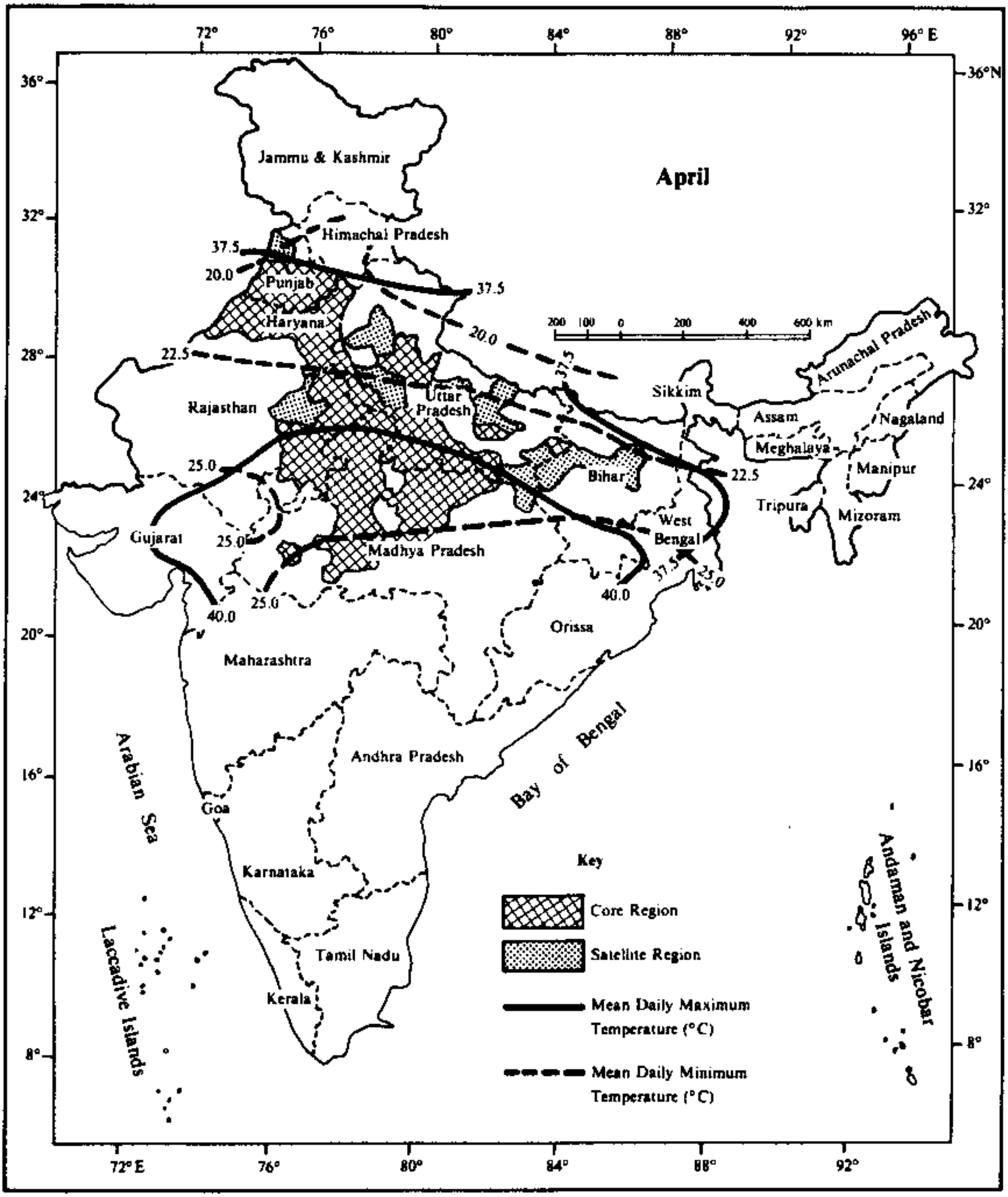


Figure 4. Mean daily maximum and minimum air temperature(°C) for April in chickpea-growing regions of India.

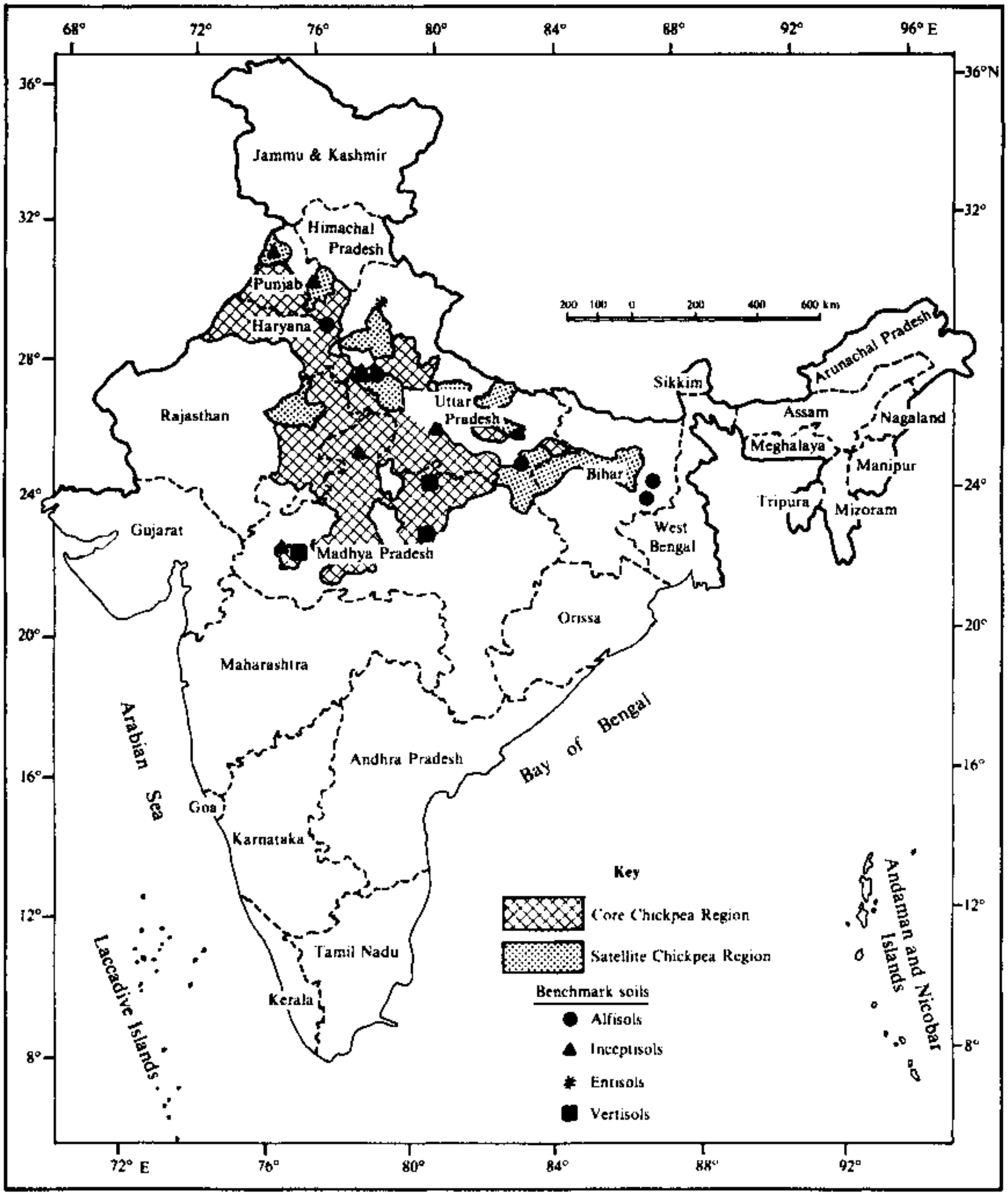


Figure 5. Benchmark soils in chickpea-growing regions of India.

cal maturity in Annigeri and the mean GDD value was 775; there was no difference in coefficients of variation (33%) using 6,8, and 10°C as base temperatures for pod initiation to physiological maturity in K 850. It may be noted that these values for coefficient of variation are too high. The mean GDD value for K 850, using 6°C as the base temperature, was 745, which is similar to that of Annigeri. The coefficients of variation using 6, 8, and 10°C as base temperatures from 50% flowering to pod initiation ranged from 60 to 90% in both cultivars, indicating that pod initiation is determined by environmental factors other than temperature alone.

The relationship between intercepted solar radiation and total dry-matter production has been studied for different crops: for example, for wheat and barley (Gallagher and Biscoe 1978), sorghum (Sivakumar and Huda 1985), pearl millet (Huda et al. 1984), and pigeonpea (Natarajan and Willey 1980). About 0.46 g of total dry matter was produced for each MJ of radiation intercepted by chickpea cv Annigeri (Fig. 6, M. Natarajan, ICRISAT, personal communication). The experiment was conducted at ICRISAT Center, Patancheru, under nonirrigated conditions. This relationship could be used to simulate chickpea total dry-matter production, but it is necessary to establish whether this relationship changes with season, location, and cultivar.

Quantified information on the effect of environmental factors on chickpea yield should be useful for building models that can be used to simulate growth and yield of chickpea. However, the impact of environmental factors on the development of diseases and pests should also be considered. For example, development of ascochyta blight in chickpea (cv ILC464) was closely related to increased temperature at Tel Hadya, Syria (Fig. 7. ICRISAT 1984); the disease began to develop when average minimum temperature exceeded 5°C and the average maximum temperature was 15°C. The disease killed almost all plants during a 3-week period when maximum temperature rose from 15° to 25°C.

Simulated Soil Water

Chickpea is able to extract moisture from deep layers of the soil profile. An adequate supply of soil moisture at the time of sowing and winter rains nearing 60-80 mm (in the Indian subcontinent) are essential for a successful chickpea crop (Singh and Das 1987). Because it is difficult to measure soil water at the time of sowing, a soil water-balance model can be used to estimate available soil water. The soil water-balance model developed by Ritchie (1972) was used to simulate soil water for ICRISAT Center and Hisar (Fig. 8). The available water-holding capacity of a medium-deep Vertisol at ICRISAT Center and an Entisol at Hisar is 150 mm. Normal rainfall from June to October is 653 mm for ICRISAT Center and 366 mm for Hisar. Sowings of chickpea were assumed on 15 October at ICRISAT Center and on 1 November at Hisar. Historical weather data for 1901-70 for Hyderabad and 1951-82 for Hisar were used to compute cumulative probability of simulated available soil water at sowing for the two locations. For ICRISAT Center, simulation of soil water was done for both rainy-season fallow and rainy-season sorghum. For Hisar, this was done only for rainy-season fallow. At ICRISAT Center, in 70% of the years there is at least 120 mm of available water under rainy-season fallow conditions and 80 mm under rainy-season sorghum (Fig. 8). Considering that normal rainfall is 42 mm and potential evaporation (PE) is 442 mm from November to February, supplemental irrigations are obviously required to achieve a reasonably good chickpea yield after rainy-season sorghum in a medium-deep Vertisol. At Hisar, the simulated available soil water after rainy-season fallow was more than 120 mm in 70% of the years. From November to February, normal rainfall there is 64 mm and normal PE 235 mm; thus good yields of chickpea can be expected at Hisar without supplemental irrigation.

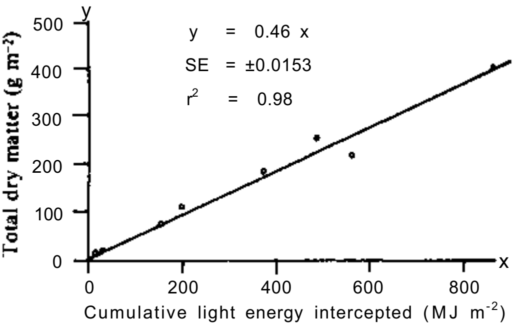


Figure 6. Relationship between intercepted solar radiation and dry-matter production for chickpea (cv Annigeri) at ICRISAT Center, Patancheru, post-rainy season 1982/83.

The information on simulated soil water at sowing is important, but the simulated daily/weekly soil water balance during the growing season would help

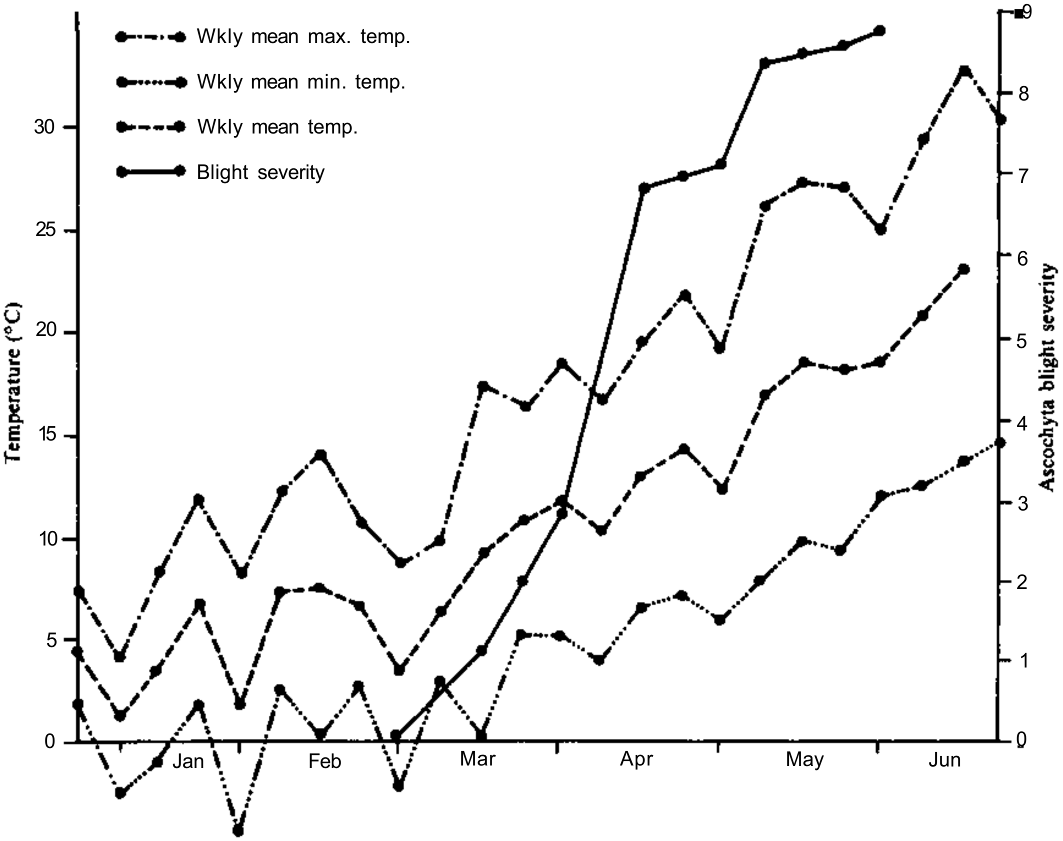


Figure 7. Development of ascochyta blight in chickpea (cv ILC 464) in relation to temperature, Tel Hadya, 1982/83 (Source: ICRISAT 1984).

us better understand whether the crop suffers from water deficits at any growth stage. Additional information on canopy development would be required to calculate the evapotranspiration component of daily soil water balance.

Simulated Grain Yield

Chickpea grain yield could be simulated on the basis of stored available soil water plus winter rains (Singh and Das 1987). Singh and Bhushan (1979) reported the following regression equation from their experimental results of 1972-73 to 1975-76 at Dehradun, using cv H 208, where experimental yield ranged between 800 and 3000 kg ha^{-1}:

$Y = 13.1\ X - 456$,

where Y = chickpea yield (kg ha^{-1})
and X = water use (mm), i.e., soil water at sowing plus rainfall during growing season.

We used this relationship to compute the cumulative probability of chickpea yield for Hisar(Fig. 9). Sowing date was assumed to be 1 November and historical weather data for 1951-82 were used. Phosphorus requirements to achieve these yields were also simulated assuming that 5 kg of phosphorus are required to produce 1 t of chickpea (Saxena 1984). In 70% of the years, simulated chickpea grain yields were at least 1.5 t ha^{-1}, and simulated phosphorus requirements were 7.5 kg ha^{-1} (Fig. 9). The simulated yields were compared with the actual yields quoted in the estimates of area and production reports. Two points were noteworthy: (1) farmers were achieving less than 1 t ha^{-1} chickpea yield in 80% of the years;

(2) the simulated maximum yield (2800 kg ha^{-1}) was similar to the experimental yield as reported by Singh and Bhushan (1979); this was much higher, however, than the mean maximum yield of 1800 kg ha^{-1} obtained by farmers. This yield gap could be reduced if proper management such as timely planting, fertilizer application, and plant protection were undertaken.

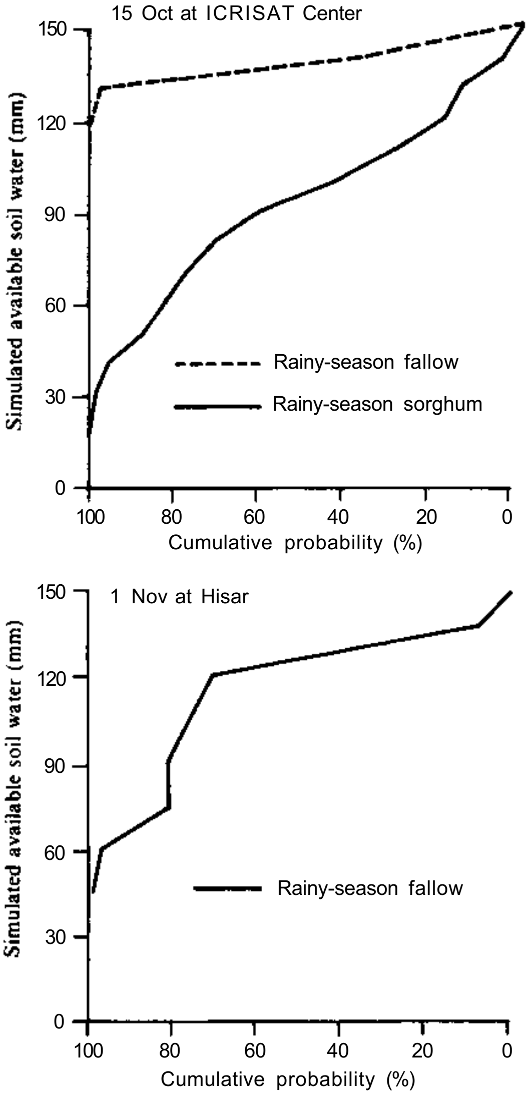


Figure 8. Cumulative probability (%) of simulated available soil water (mm) at sowing for ICRISAT Center, Patancheru (using historical data for Hyderabad, 1901-70), and Hisar (using historical data, 1951-82).

The water-use efficiency (WUE) of nonfertilized chickpea crops grown on stored soil water at ICRISAT Center, Patancheru, is between 7.6 and 9.2 kg grain ha^{-1} mm^{-1} (Saxena 1984). We have used the WUE value of 8 kg of grain ha^{-1} mm^{-1} to compute cumulative probability of chickpea yield for ICRISAT Center under both rainy-season fallow and rainy-season sorghum (Fig. 9). Historical weather data for 1901-70 were used and the sowing date was assumed to be 15 October. Maximum yields under both rainy-season fallow and rainy-season sorghum were about 3 t ha^{-1}. The percentage of maximum yield was computed by dividing individual-year simulated value by the maximum simulated yield. In 70% of the years, at least 40% of the maximum yield was simulated under rainy-season fallow and 35% of the maximum yield under rainy-season sorghum. Phosphorus requirements for achieving these yield levels were also simulated (Fig. 9).

Using the WUE value of 8 kg grain ha^{-1} mm^{-1}, chickpea yields were also simulated from 1974-75 to 1982-83 for ICRISAT Center. Simulated yields were compared with actual yields reported in ICRISAT Annual Reports for these years (Table 1). Simulated values were within ± 20% of actual yields in 50% of the years. The lowest chickpea yields were simulated for 1976/77 and 1980/81 under rainy-season sorghum. These are due to low winter rainfall from November to February, which was 30 mm in 1976/77 and 24 mm in 1980/81.

Table 1. Actual and simulated chickpea yield at ICRISAT Center, Patancheru, under residual moisture for 1974/75 to 1982/83.

	Chickpea yield (kg ha^{-1})		
		Simulated	
Year	Actual	After rainy-season fallow	After rainy-season sorghum
1974/75	2596[1]	3024	2928
1975/76	1878[1]	2248	2176
1976/77	2654[1]	1258	578
1977/78	1963	1805	1238
1978/79	1342	1715	1459
1979/80	1015	1743	1447
1980/81	1499	1265	658
1981/82	1250	1232	1104
1982/83	2460	1636	1268

1. Cultivar other than Annigeri; all other results reported here are from cv Annigeri.

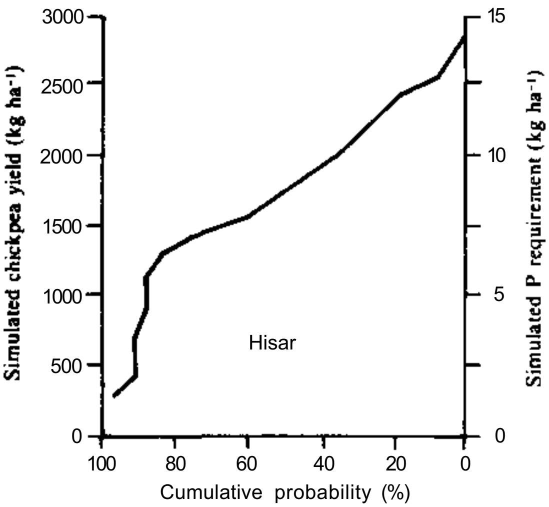
The water-use and yield relationship studies discussed above can be used to screen environments for production potential. Simulated data in Table 1 show, for example, that in a medium-deep Vertisol, sequential crops (sorghum in rainy season and chickpea in postrainy season) are possible in three years out of nine without loss in chickpea yield.

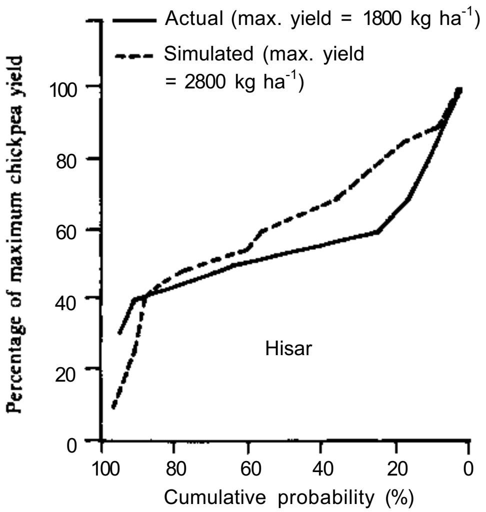
Simulated chickpea yields were lower by 3-52% than actual experimental yields in four years, particularly so in 1976-77 when rain during October-February was low (30 mm). It is possible that in such low-rainfall years, supplemental irrigations were applied in field experiments, but these were not considered in the simulation because actual data were not available on date and amount of irrigation. This suggests that such minimum essential information from field experiments should be recorded, so that they can be included in the simulation and the results can be generalized.

Pigeonpea

World pigeonpea production data (FAO 1982) indicate 14 pigeonpea-growing countries, which are grouped into four categories:

- India, which produced 90% of the world





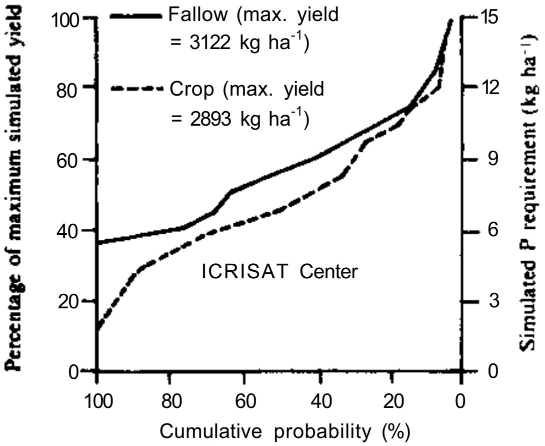


Figure 9. Cumulative probability (%) of simulated chickpea yield and simulated P requirements for Hisar and ICRISAT Center, Patancheru. Sowing dates assumed: for Hisar, 1 November; for ICRISAT Center, 15 October. Historical weather data used: 1901-70, Hyderabad, for ICRISAT Center; 1951-82 for Hisar.

production;
- Kenya and Uganda, which individually contributed 2-3% and together contributed *5%* of the world production;
- Burma, the Dominican Republic, and Malawi, which individually contributed 1-2% and together contributed 4% of the total world production;
- Other countries, in which individual and total share of world production was below 1%.

The agroclimatic environment of pigeonpea has been discussed by Reddy and Virmani (1981). Chickpea is usually grown under stored soil moisture, whereas pigeonpea is sown mainly as a mixed crop or as an intercrop at the beginning of the rainy season. Thus, the soil becomes charged as the rainy season advances and as the crop grows. Intermittent wetting and drying, including periods of waterlogging, are experienced by pigeonpea, which, however, continues to grow after the rains stop, with pod filling continuing under progressively depleting soil moisture.

Since 90% of the world pigeonpea production comes from India, we have studied the distribution, area, production, and agroclimatic environment of the pigeonpea-growing regions in India (Fig. 10). Uttar Pradesh, Maharashtra, Karnataka, and Madhya Pradesh contributed about 80% of the pigeonpea production in India (Bose 1981). Easter and Abel (1973) demarcated pigeonpea growing regions into "core" and "satellite", which were defined earlier for chickpea. Pigeonpea-growing areas are located within the 600-1400 mm annual rainfall zone (Reddy and Virmani 1981).

Average length of the growing season in India was prepared by the Agroecological Zones Project of FAO (1979) (Fig. 11). Growing period is defined as the number of days during a year when precipitation exceeds half the potential evapotranspiration, plus a period required to evaporate an assured 100 mm of water from excess precipitation stored in the soil. The lengths of pigeonpea-growing periods for core districts in Uttar Pradesh, Bihar, Madhya Pradesh, and eastern Maharashtra are between 120 and 180 days (Fig. 11). Most of the satellite pigeonpea-growing regions in the states of Karnataka, Andhra Pradesh, and Maharashtra have growing periods of 90-120 days. The benchmark soils map of India (Murthy et al. 1982) has been superimposed on the map of the pigeonpea-growing regions (Fig. 12). The predominant soils in these regions are Alfisols, Inceptisols, and Vertisols.

Isoclimes of Pigeonpea-Growing Areas in West Africa

The Inter-African Committee for Hydraulic Studies (CIEH 1979) defined three major bioclimatic zones in West Africa:

a. The Southern Sahelian zone, with a growing season of 75-90 days;
b. The Sudanian zone, with a growing season of 90-165 days;
c. The Northern Guinean zone, with a growing season of 165-210 days.

Based on a study of the monthly moisture availability index for rainy season cropping at 15 locations (Virmani et al. 1980) representing five West African countries, Reddy and Virmani (1981) suggested that the southern part of the Sudanian bioclimatic zone, with a growing season of 120 days, and the Northern Guinean zone, with about 180 days, are likely to provide a suitable growing environment for pigeonpea. The crop is likely to do well on deep, heavy-textured soils in these regions.

Future Research Needs

- To delineate the isoclimes for regions growing chickpea and pigeonpea.
- To identify a few benchmark locations that represent a wide range of agroclimatic environments in which the two crops are grown, for testing improved management practices and promising genotypes.
- To compute the frequency of different water availabilities in space and time, using simple soil water-balance models.
- To generate cumulative probabilities of yield potential of the two crops, using water-use and yield relationships for various locations, and thus to help expedite the transfer of technology.
- To collaborate with different national and international institutes to document the existing knowledge on these crops, which can be used for building crop simulation models.

Acknowledgments

Thanks are due to Mr M. Shankaraiah for cartographic work and to Mr J.G. Sekaran for assistance in analyzing the data.

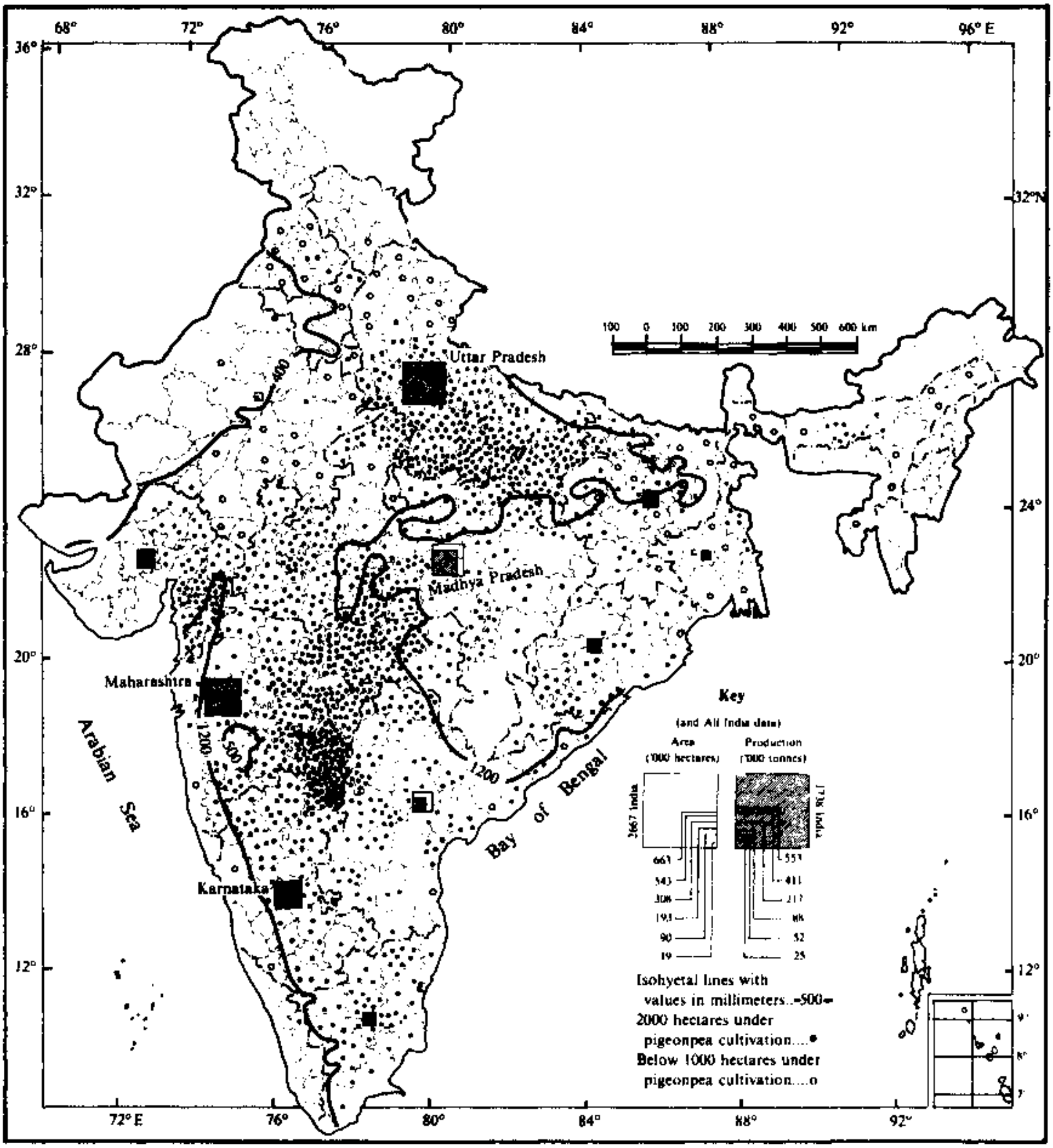


Figure 10. Distribution, area, and production of pigeonpea in India.

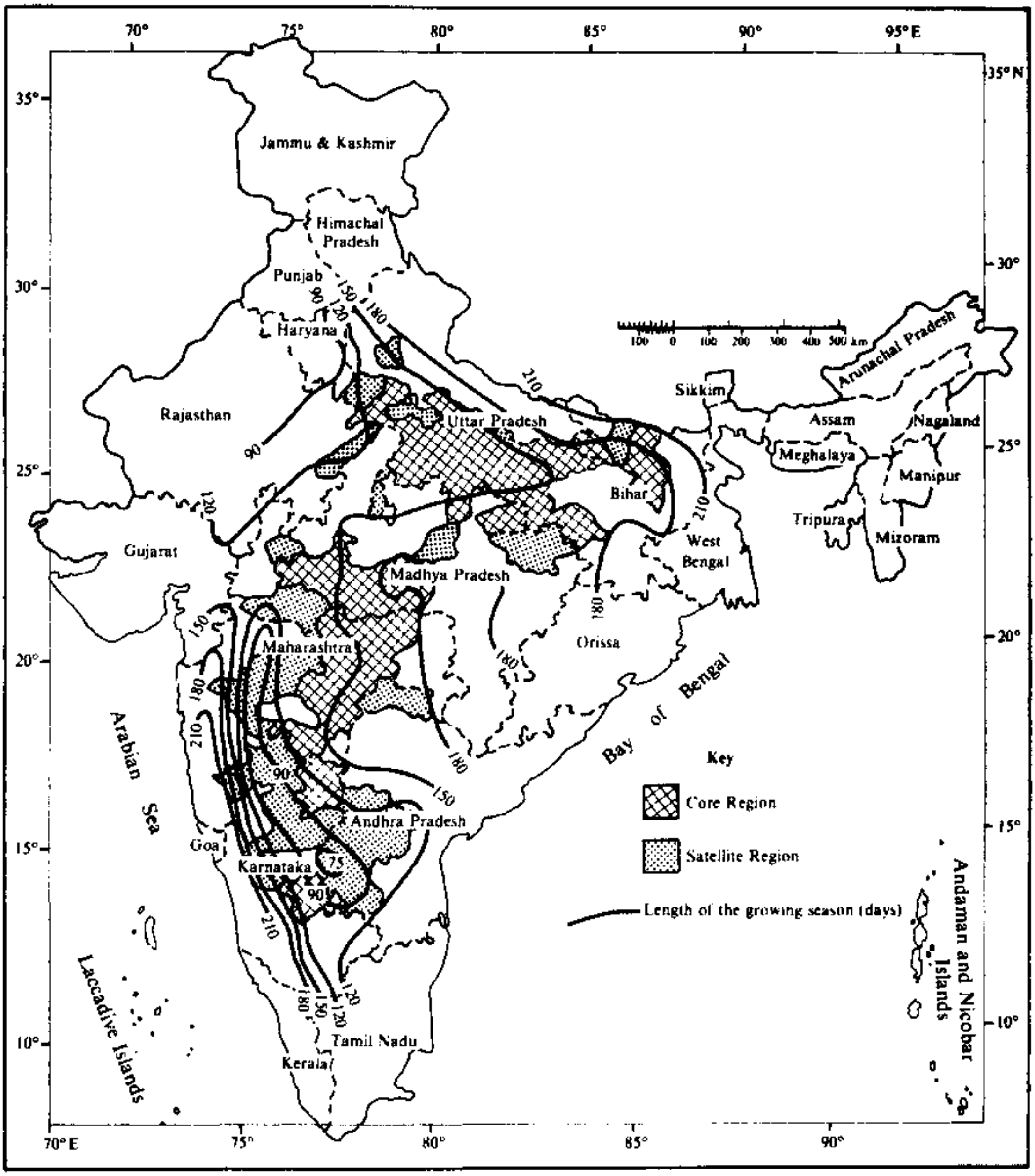


Figure 11. Length of the growing season in pigeonpea-growing regions in India.

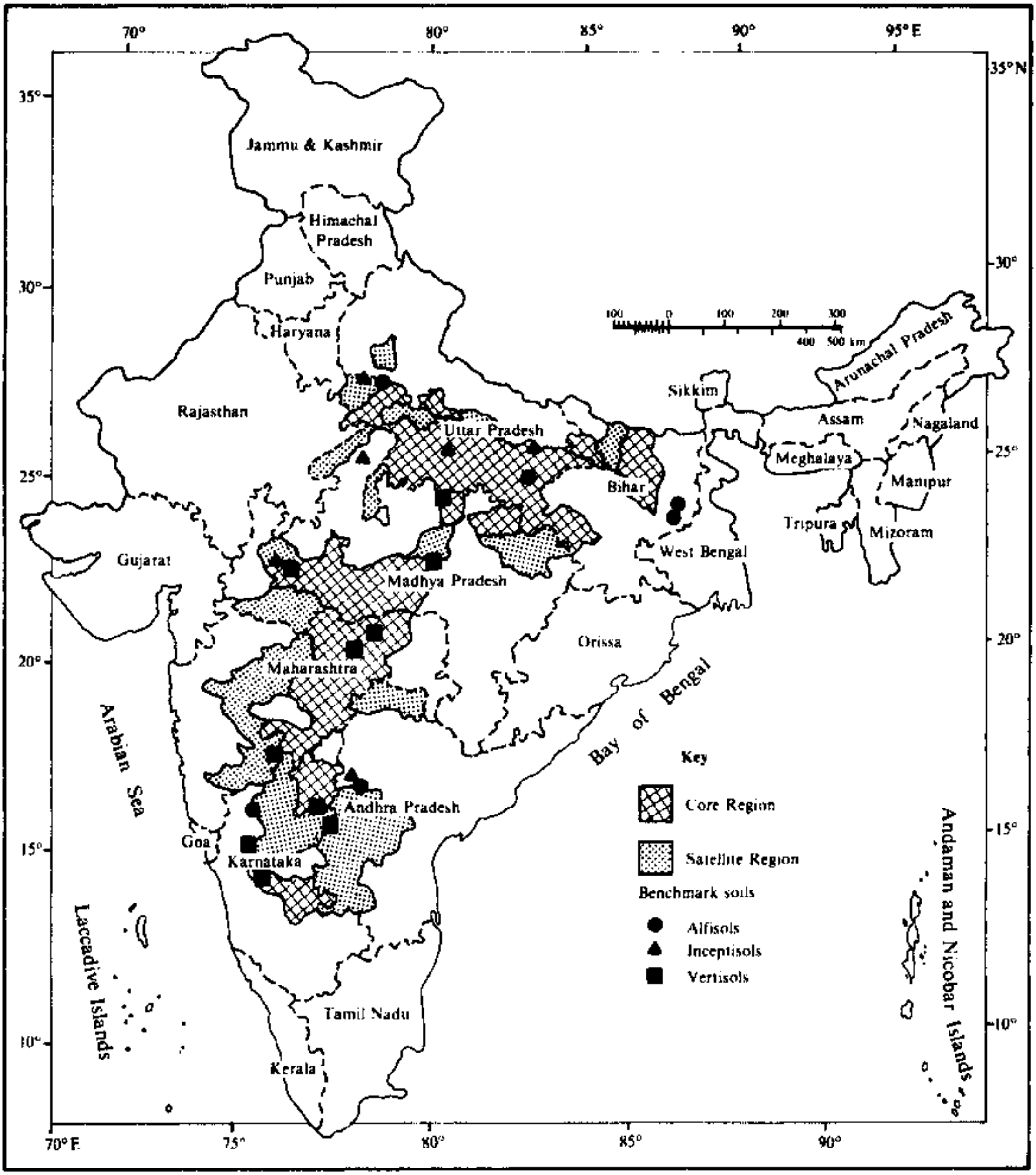


Figure 12. Benchmark soils of pigeonpea-growing regions in India.

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Photothermal Effects on Flowering in Chickpea and Other Grain Legumes[1]

R.J. Summerfield[2], E.H. Roberts[2], and P. Hadley[3]

Abstract

Traditionally, photoperiod has been considered to have the most significant effect on flowering in chickpea. But wherever studies have been sufficiently extensive, major effects of temperature on flowering have been noted. Irrespective of species, there are large genetic differences in relative sensitivity to photoperiod and/or temperature. In quantitative long-day legumes, such as chickpea, vernalization can also hasten flowering in sensitive genotypes. A daunting plethora of seemingly complex responses to, and interactions between, these three factors (photoperiod, temperature, and genotype) have been published. However, recent research on diverse genotypes of each of soybean, cowpea, chickpea, and lentil (and reanalyzes of previously published data on pea, common bean, and mung bean) has shown that simple quantitative models can describe the modulation of flowering by photothermal conditions over wide ranges of both photoperiod and temperature. These relations describe response surfaces that can be used as a basis for screening the flowering responses of large numbers of genotypes at a small number of carefully selected field sites. These recent findings and their implications are described and discussed, with emphasis on crop improvement in chickpea.

Introduction

Nearly 10 million ha per year have been sown to chickpea (*Cicer arietinum* L.) throughout the world during the last decade (FAO 1981); this overall figure includes annual fluctuations within the ecologically diverse production regions of India, West Asia, the Mediterranean, eastern Africa, the Americas, and Europe (Rao and Subba Rao 1981). The crop is often described as "essentially subtropical" (Kay 1979) and best adapted to relatively cool and dry conditions. It is cultivated almost exclusively on residual soil moisture during the postrainy seasons of subtropical winters, or in spring and summer months in Mediterranean environments (Smithson et al. 1985). Within these situations, chickpea encounters widely different physical and biological environments that exert profound influences on crop growth, development, and productivity (Saxena 1984).

In northern India, the principal producing area, the crop is sown from October to November and can produce dry seed yields up to 5000 kg ha^{-1} in a growing season of 160-170 days. Where the growing season is restricted to 100 110 days, southward by the earlier onset of heat and moisture deficits and eastward by the later beginning of rains, potential seed yields of rainfed crops are reduced to between 1500 and 2000 kg ha^{-1}. Thus, maximum productivity declines from about 30 to about 20 kg seed ha^{-1} day^{-1} (Smithson et al. 1985). The crop is seldom irrigated and so the winter cropping season is not "open-

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ended" (being succeeded, within a few weeks, by the hot, arid summer season). Thus, genotypes of too long a duration or those planted too late in the season undergo "forced maturation," and their yields suffer accordingly (Sheldrake and Saxena 1979). In these circumstances, and in the shorter growing season of peninsular India, an appropriate crop duration largely determines the suitability of genotypes to environment, and date of planting is a major agronomic determinant of their relative yields.

Outside the Indian subcontinent, chickpea is traditionally sown in spring, although consistently large yield improvements have recently been demonstrated in the Mediterranean basin from sowing in winter, provided the crop is protected against the ravages of ascochyta blight (Hawtin and Singh 1984; Nene 1984). The environments, growth durations, and seed yields experienced by and characteristic of traditional spring-sown and novel winter-sown crops in Syria share some similarities with chickpea crops grown in peninsular and northern India (Table 1); this compatibility may be exploitable in crop improvement programs.

In addition to the wide range of environments in which chickpea is cultivated, there are two different types of chickpea with, perhaps, different centers of diversity (Ramanujam 1976), and these are also grown in, and recognized to be best adapted to, different regions. The "desi" types—with relatively small, angular seeds and rough, usually yellow to brown testas—constitute about 85% of world annual production and are confined to the Indian subcontinent, Ethiopia, Mexico, and Iran. The "kabuli" (or garbanzo) types—with larger, more rounded, cream-colored seeds—account entirely for the crops of Afghanistan through western Asia to northern Africa, southern Europe, and the Americas (except Mexico). From this combined array of genetic and environmental diversity, no individual genotypes that are widely adapted have been identified (Singh et al. 1980); major genotype x environment interactions are common between locations and between seasons at the same location (Byth et al. 1980). Such specific adaptations can limit crop improvement efforts seeking to develop and select cultivars from a centralized breeding program (Saxena 1984).

It is widely recognized that chickpea genotypes differ inherently in relative longevity and that durations to flowering and reproductive maturity vary appreciably depending on sowing date, latitude, and

Table 1. Characteristics of chickpea crops and their photothermal environments in selected locations (compiled from Saxena 1984 and other sources).

Attribute of crop/climate	Hyderabad, India (17°32'N)	Hisar, India (29°10'N)	Aleppo, Syria (36°11'N)	
			Spring-sown	Winter-sown
Sowing date	Oct	Oct	Feb-Mar	Nov-Dec
Harvest date	Feb	Mar-Apr	Jun-Jul	May-Jun
Approximate crop duration (days)	100	150-180	<120	160-180
Typical rainfall (mm)				
Average presowing total	600	370	300	250-450[1]
Range during crop growth	40-100	80-90	25-50	-
Approximate photoperiod				
At sowing	11 h 34 min	11 h 16 min	11 h 00 min	10 h 33 min
At onset of flowering	11 h 09 min	10 h 10 min	12 h 30 min	11 h 30 min
At crop maturity	11 h 24 min	12 h 44 min	14 h 33 min	14 h 17 min
Average mean maximum and minimum air temperatures (°C)				
At sowing	30/20	35/17	17/5	18/6
At onset of flowering	28/13	20/5	25/9	21/4
At crop maturity	32/16	37/20	36/18	32/16

1. Seasonal totals and "well distributed" (Saxena 1984).

altitude; flowering can be as early as 30 days after sowing (DAS) or as late as 100 DAS (Summerfield and Roberts 1985a). In some genotypes, the formation of so-called "pseudo-flowers"—buds that desiccate, turn yellow, and abort before opening (Aziz et al. 1960)—can effectively prolong vegetative growth, which may explain some of the anomalies encountered when interpreting flowering records from multilocational trials (Smithson et al. 1985). Then again, the development sequence from initiation until differentiated florets are visible to the naked eye can vary from a few days in "warm" weather to several weeks in "cold" conditions (Moncur 1980). A broadly relevant international chickpea breeding program must be founded on, and exploit, a sound understanding of the ecophysiological basis of genotype * environment interactions (Byth et al. 1980); an appreciation of the relative importance of different traits and responses among diverse germplasm is thus essential. The traits that influence the timing of phenological events are especially important. With chickpea, the main problems include:

1. Quantifying the relative importance of different environmental factors in modulating phenology.
2. Determining the availability of genotypes within desi and kabuli germplasm (including local landraces that most farmers still grow [Hawtin et al. 1980] and, perhaps, the wild species of Cicer), which are particularly sensitive or insensitive to critical environmental factors.
3. Assessing the agronomic significance and regulation of "pseudo-flower" formation.
4. Determining the relative importance and mode of regulation of floral initiation and expansion of initiated primordia, which culminate, in time, in the appearance of open flowers.
5. Ascertaining the traits and responses contributing significantly to the efficient exploitation of space and time in genotypes planted on unconventional dates.
6. Verifying appropriate screening techniques for large numbers of (segregating) germplasm which are reliable, inexpensive, and can be carried out in one or a few field locations.
7. Defining methods and technology to improve the efficacy of artificial hybridization, which up to now has often given erratic results because of temporal changes in pollen viability (Eshel 1968) and receptivity of the stigmatic surface (Turano et al. 1983).

We concentrate in this paper on the subject matter in 1,2,6, and 7, citing examples for grain legumes in general and emphasizing recent findings for chickpea in particular.

Environmental Regulation of Flowering in Grain Legumes

Traditionally, in all legumes, photoperiod has been the environmental factor considered to have the most significant effect on flowering, and important differences between species (Table 2) and genotypes have been established with respect to:

1. The optimum photoperiod—that at which flowering occurs soonest.
2. Photoperiod sensitivity—the delay or hastening in flowering per unit change in photoperiod.
3. The critical photoperiod—that above or below which flowering is first delayed (quantitative response) or arrested (qualitative response).

Unfortunately, ambiguous and inconsistent use of these terms and others intended to describe relative indifference to photoperiod (e.g., "day-neutral") have led to considerable confusion in the international literature on grain legume crops (Summerfield and Wien 1980).

Species of grain legume that originate from more or less temperate climates (in Asia, the Mediterranean, or southern Europe; e.g., see Smartt 1984) are usually quantitative, long-day plants and are also often responsive to cold temperature vernalization (Table 2). On the other hand, maintaining a strong correlation with taxonomic grouping, members of the Phaseoleae of tropical origin do not have a vernalization requirement and, for the most part, are quantitative short-day plants (Table 2). However, daylength-indifferent genotypes of most species have now been discovered from within germplasm collections or are produced by hybridization, and not all long-day genotypes respond to vernalization (Summerfield and Roberts 1985b). And wherever studies have been sufficiently extensive, major effects of temperature on flowering have also been shown (Summerfield and Wien 1980; Summerfield et al. 1980; Summerfield and Roberts 1985a, b).

Breeders of grain legumes recognize the importance of timely flowering and may have even selected for it (consciously or otherwise) in selecting for adaptation to particular sites, supposedly chosen to represent particular regions rather than specific combinations of photoperiod and temperature. This

Table 2. Flowering responses[1] of grain legume crops to photoperiod and vernalization (for sources, see Summerfield and Roberts 1985b).

			Photoperiodic response[2]					Vernalization response	
			Short-day		Long-day				
Species	Tribe	Center of origin	Obligate	Quanti-tative	Obligate	Quanti-tative	Day neutral[3]	Obligate	Quanti-tative
Arachis hypogaea	Aeschynomeneae	S. America/Africa	-	-	-	-	*	-	-
Lupinus spp	Genisteae	Africa/Mediterranean	-	-	-	*	*	-	*
Cicer arietinum	Cicereae	Asia	-	-	-	*	*	-	*
Lens culinaris	Vicieae	Asia/Mediterranean	-	-	-	*	*	-	*
Vicia faba	Vicieae	Asia/Mediterranean	-	-	-	*	*	-	*
Pisum sativum/arvense	Vicieae	Asia/Mediterranean	-	-	-	*	*	*	*
Cajanus cajan	Phaseoleae	Africa/India	*	*	-	-	*	-	-
Glycine max	Phaseoleae	Manchuria/China	*	*	-	-	*	-	-
Phaseolus lunatus	Phaseoleae	Mexico/Guatemala	-	*	-	-	*	-	
Phaseolus vulgaris	Phaseoleae	Asia	-	*	-	-	*	-	-
Psophocarpus tetragonolobus	Phaseoleae	Papua New Guinea	-	*	-	-	-	-	-
Vigna mungo/radiata	Phaseoleae	Asia/India	*	*	-	-	*	-	-
Vigna unguiculata	Phaseoleae	Africa/India	*	*	-	-	*	-	-

1. An asterisk denotes the response type indicated has been reported; a dash that it has not been reported; a blank space that it has not been measured.
2. Obligate = response changes at a discrete critical value; quantitative = response gradually changes over a range of values.
3. Indicates indifference to photoperiod.

traditional approach requires that selections are grown and tested at a number of sites and for several seasons to take account of climatic variations—a protracted, expensive and now, we believe, unreliable strategy. However, by exploiting recent research data (Hadley, Roberts et al. 1983, 1984 for cowpea and soybean; Summerfield and Roberts 1985c for soybean; Roberts et al. 1985, for chickpea; Summerfield, Muehlbauer, and Roberts 1984, and Summerfield, Roberts, et al. 1985 for lentil), we suggest that screening for responsiveness to photothermal effects on flowering can be rapid, inexpensive, and reliable—as we discuss later.

Illuminance, Photoperiodic Response, and Artificial Hybridization in Chickpea

A traditional limitation to crop improvement efforts in chickpea has been a slow rate of generation turnover, and most research has been restricted to advancing one generation per year. In addition, off-season nurseries are often prohibitively expensive, sites may be inaccessible, and quarantine restrictions may hinder the movement of germplasm. The internationally oriented chickpea improvement program at ICRISAT soon recognized these major problems and other severe restraints to progress, such as the widely used, but tedious, practice of sowing crossing blocks on several dates to try and ensure simultaneous flowering of diverse germplasm (Auckland and van der Maesen 1980).

By exploiting the quantitative long-day response to photoperiod in chickpea (Table 2), ICRISAT scientists developed the first "accelerated generation turnover (AGT)" technique for this crop by extending natural daylengths to 24 hours using incandescent bulbs (60-100W) suspended on a 1.5 × 1.5-m grid about 60 cm above the crop canopy (Sethi et al. 1981). Parallel research (N.P. Saxena, L. Krishnamurthy, and A.R. Sheldrake, unpublished) concluded that time to flowering was affected by the illuminance of artificial light used and that the critical illuminance was greater in later-flowering (5-6 lux) than in early-flowering (1 -2 lux) genotypes. We propose below an alternative interpretation to ICRISAT's data.

Responsiveness to Dim Light: How Dark is Dark?

In photoperiodism, a plant must discriminate between day and night (an illuminance detected as darkness), measure the duration of one or both, and in response control some process such as flowering (Salisbury 1981). We have recently reviewed the effects of illuminance on flowering in lentil and soybean (Summerfield, Muehlbauer, and Roberts, 1984; Summerfield and Roberts 1985c), which respond to photoperiod as quantitative long- and short-day plants, respectively. We have proposed an alternative and, we believe, more plausible explanation for differences in apparent sensitivity of these species to dim light. Our alternative explanation seems equally convincing for chickpea, as we discuss below.

Irrespective of the species involved, genotypes have often been evaluated by growing them at increasing distances from a point source of light (i.e. along an illuminance gradient) and their times to flowering (f) have then been related to illuminance. For example, in field investigations with soybean (Major and Johnson 1974) and chickpea (ICRISAT 1981) natural daylengths were extended to 24 hours using lamps suspended above field plots. Relative sensitivity to illuminance was then estimated by the delay or hastening of flowering in progressively brighter regimes (i.e., in those regimes where plants were better able to perceive the long days imposed on them). Using this criterion, both groups of researchers concluded that there was significant genotypic variation in sensitivity to illuminance.

Notwithstanding these interpretations, in many photochemical and photobiological processes, responses are approximately proportional to the logarithm of incident illuminance (Withrow 1959) rather than to the illuminance itself. Furthermore, as we describe later, photoperiodic phenomena in grain legumes are now known to be related more simply to the rate of progress towards flowering (1 / f) than to time to flowering (f). Thus, data can be expressed in these terms to further clarify relations between illuminance and flowering.

We next consider the relations between rates of progress toward flowering and log illuminance that might be expected when plants differing inherently in their sensitivity to photoperiod are grown in experiments in which short natural days are extended by light of different illuminance. Figure la shows the responses predicted for quantitative short-day (soybean) and quantitative long-day species (chickpea) which, for simplicity, are assumed to have the same threshold (T) and saturation (S) illuminance values. In quantitative short-day species, the time taken to flower will be delayed when relatively short natural days are extended by artifi-

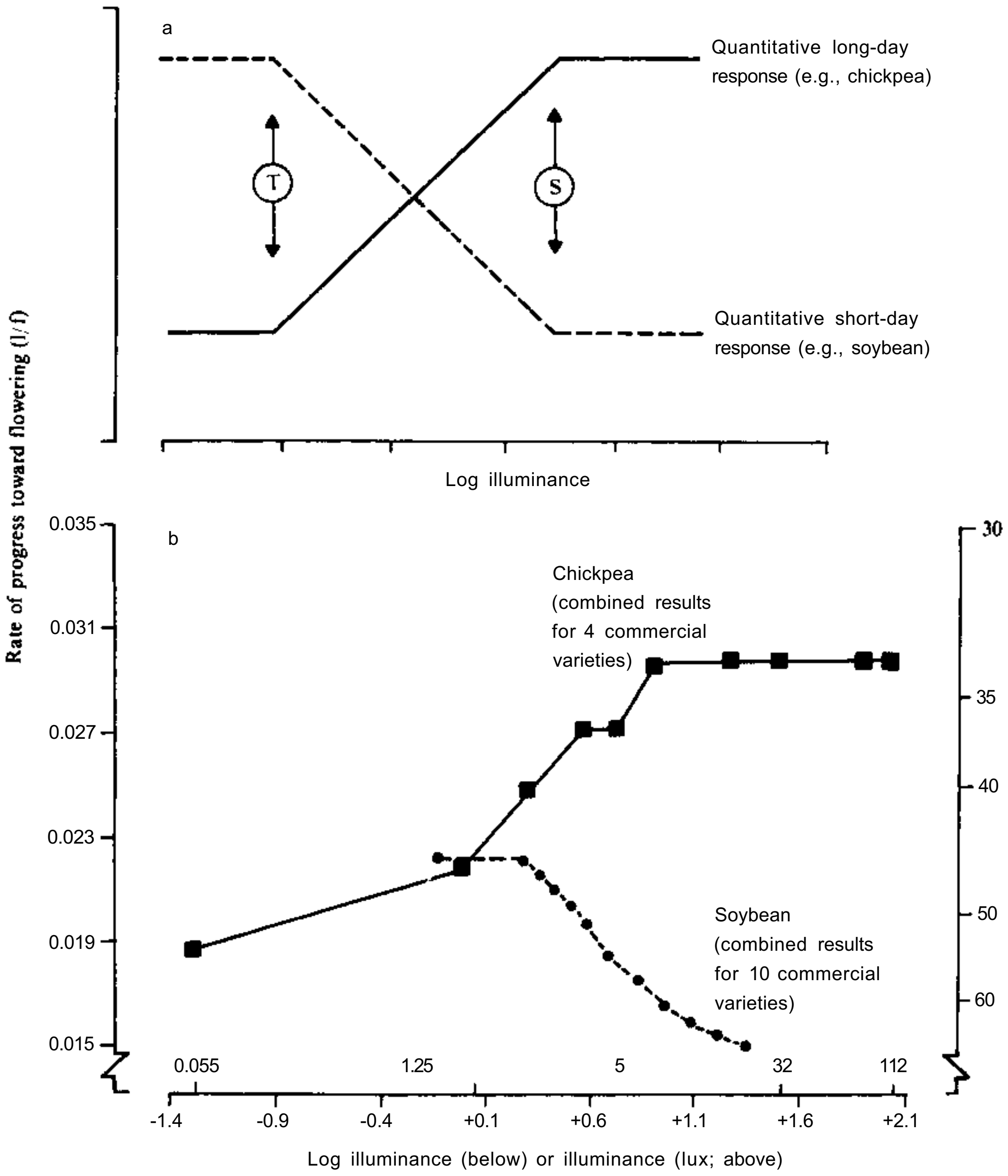

Figure 1. (a) Schematic representation of the relations between log illuminance and rates of progress toward flowering (1/f) predicted for quantitative short- or quantitative long-day species in experiments in which relatively short days are extended by supplementary illumination of various illuminance values. T denotes threshold and S denotes saturation illuminance values (see text); and (b) relations between log illuminance of supplementary light extending natural photoperiods to 24 h and rate of progress towards flowering (l/f) in soybean (combined results for ten commercial cultivars, calculated from Major and Johnson 1974) and chickpea (combined results for four cultivars, calculated from ICRISAT 1981).

cial supplementary illumination. Conversely, in quantitative long-day plants, flowering will be hastened when relatively short natural days are extended. The illuminance needed to saturate the photoperiodic response (S) can be defined as that illuminance above which there is no significant increase (in short-day species) in the time taken to flower. The threshold illuminance (T) we consider is that illuminance below which there is no further significant hastening (in short-day species) or delay (in long-day species) in time to flowering. A full discussion of these relations and those predicted for qualitative responses to photoperiod is presented elsewhere (Summerfield, Muehlbauer, and Roberts 1984).

Reexamination of data published for chickpea (ICRISAT 1981) and soybean (Major and Johnson 1974) reveals trends strikingly similar to those predicted here for both quantitative long-and short-day species (Fig. lb). We cannot determine unequivocally the threshold and saturation illuminance values for these species from the data available. Nevertheless, it seems that the threshold illuminance, in both cases, is about 1 2 lux. Irrespective of the true threshold and saturating illuminance values for any species, however, the very rapid changes in illuminance during periods of twilight (Withrow 1959) mean that threshold values as small as 1 lux are likely to be exceeded from about 30 min before sunrise until 30 min after sunset; saturation values, even as large as 1000 lux, would probably be achieved within 10 min after sunrise (first appearance of solar disc) and, on clear but not cloudy days, be maintained until 10 min before sunset (Salisbury 1963). The regulatory significance of such rapid changes in illuminance (Fig. 2) for reproductive development in plants seems difficult to envisage, particularly when the values are subject to transitory variations in weather.

Figure 3 considers an alternative hypothesis which follows from this discussion, to explain the seemingly different responses of chickpea cultivars to dim light (see also Summerfield, Muehlbauer, and Roberts 1984). Figure 3a shows the times to flowering for genotypes of different relative maturity in the field (well known and extensively used by ICRISAT researchers) in different photothermal regimes (Table 3). When cultivars differing in this way are grown along an illuminance gradient (Fig 3b), and if all of them have similar respective threshold and

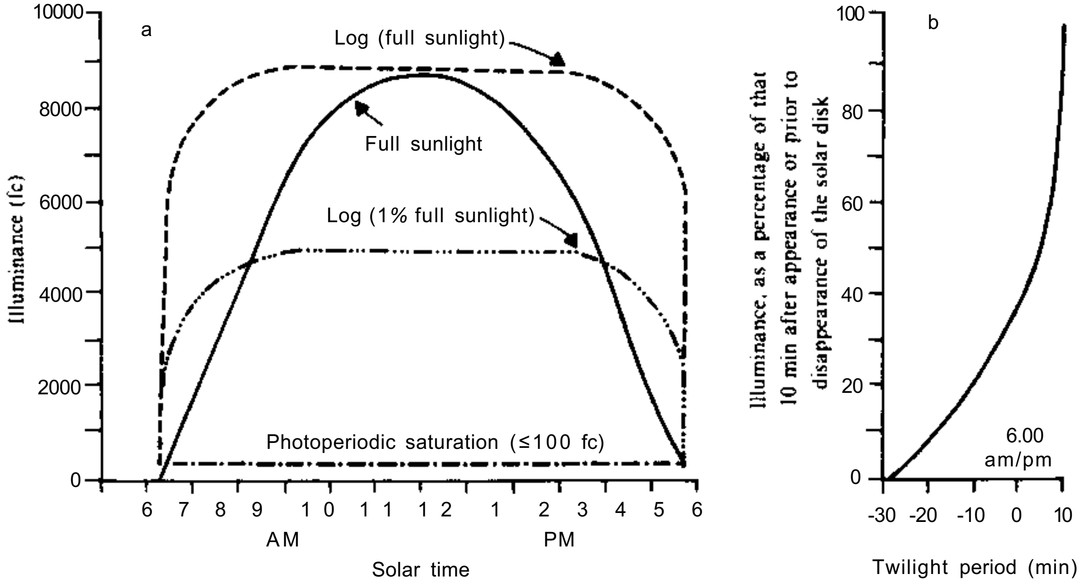

Figure 2. (a) Linear and logarithmic plots of sunlight illuminance on a horizontal surface for clear days at the spring and autumnal (fall) equinoxes; temporal trends in illuminance equivalent to 1% full sunlight (a heavily overcast sky) and the illuminance thought to more than saturate photoperiodic responses in plants are also shown for comparison; and (b) time course for twilight illuminance at dawn and dusk (0 - time of appearance or disappearance of edge of solar disk). Both figures recalculated and redrawn in part after Withrow 1959.

saturation illuminance values, the relations between the illuminance of supplementary light and days to flowering will inevitably be different: cultivars less sensitive to photoperiod show smaller response gradients. We suggest that this alternative explanation is conceptually simpler than one that involves differences in responsiveness to dim light per se, and we have proposed further experiments designed to test this concept (Summerfield, Muehlbauer, and Roberts 1984).

Those data have practical implications for artificial manipulations of photoperiod either in controlled environments or in the field. Breeders may wish their parental lines to flower sequentially when planted on the same date in one location so that the workload of hybridization is spread and crosses between early- and late-flowering parents are facilitated. Seeding plants along an illuminance gradient may achieve this objective, improving the flexibility and efficiency of the breeding program.

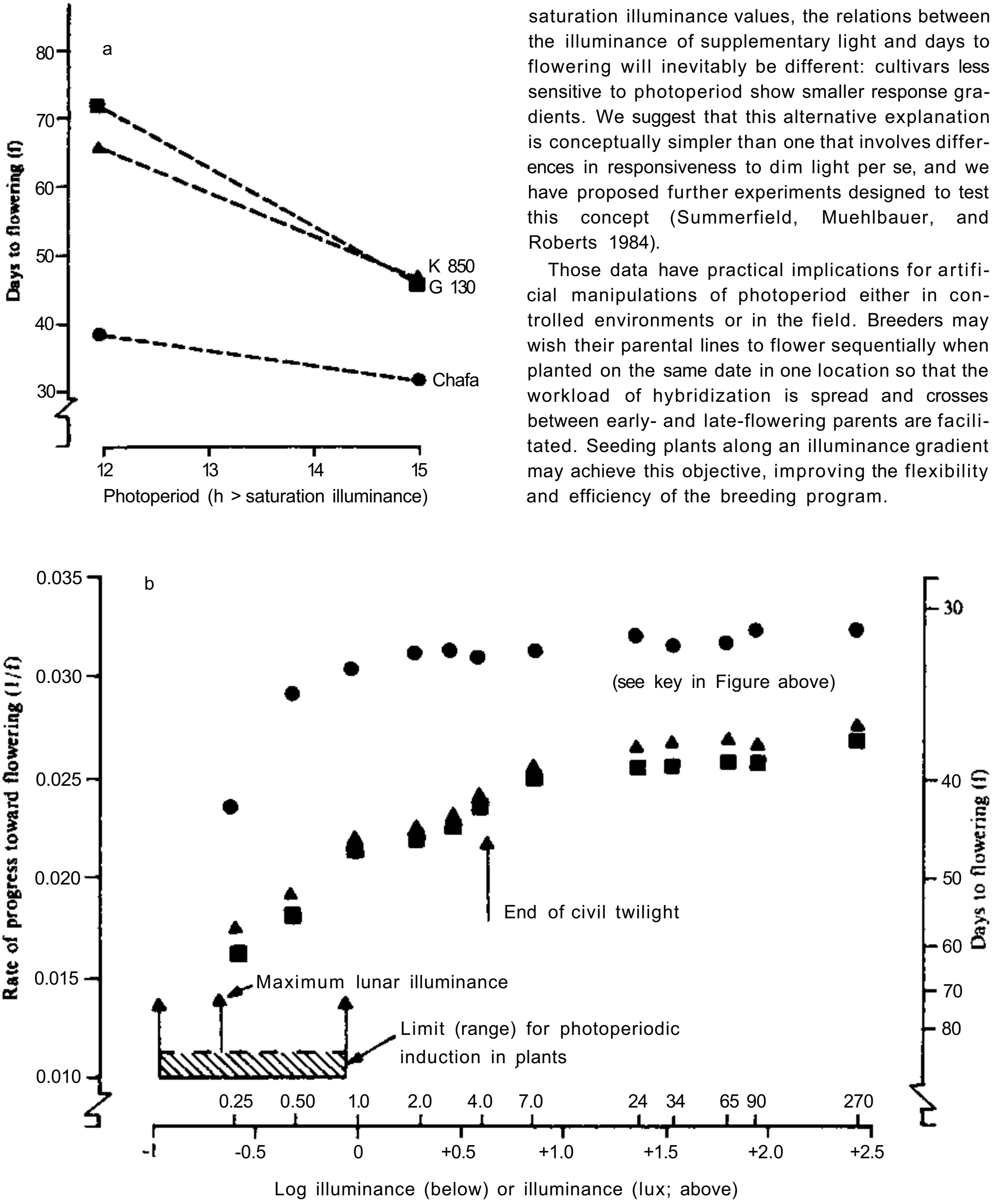

Figure 3. Relations between (a) photoperiod (h greater than saturation illuminance) and days to flowering (f) for three chickpea genotypes of different field maturity (ICRISAT 1981) and sensitivity to photoperiod (see Table 3); and (b) log illuminance and rate of progress toward flowering (1/f for the same trio of genotypes grown along an illuminance gradient which extended natural days at Hyderabad (17°32'N) to 24 h (recalculated from ICRISAT 1981).

Table 3. Effects of photoperiod (h) and mean temperature (t in ° C) on times to first flowering (days from sowing) in three chickpea genotypes. See also Figure 3.

	Days to first flowering				Photoperiod sensitivity	
	t = 14°C		t = 26°C			
Genotype	12 h	15 h	12 h	15 h	Days[1]	Ranking[2]
Chafa	47.8	37.5	29.0	24.9	4.1-10.3	1
K 850	84.0	55.5	47.8	37.0	10.8-28.5	2
G 130	94.5	56.2	48.6	36.0	12.6-38.3	3

1. The delay in flowering in short and long photoperiods in warm and cool regimes.
2. Relative sensitivity to photoperiod from 1 (least sensitive) to 3 (most sensitive).

Photothermal Effects on Flowering in Chickpea and Other Grain Legumes

The responses of higher plants to temperature and photoperiod are well recognized as having adaptive significance, especially in those species where intense artificial hybridization pressures have not yet "relaxed" or removed photothermal responsiveness sufficiently to facilitate the dissemination of exploited species into a wide range of agricultural environments. Many of the economically important species of grain legumes retain strong photothermal responses, which successive generations of plant breeders have tried to ignore, tolerate, or manipulate in rather empirical ways (Summerfield and Roberts 1985b). A major limitation in grain legume breeding has been the lack of an adequate basis to quantify these responses and to devise simple, rapid, economically attractive, and reliable field-based screening techniques suitable for large numbers of segregating germplasm. In the discussion which follows, we suggest that by exploiting recent findings on the quantitative predictability of photothermal responsiveness (for flowering), plant breeders now have the ability not only to screen their germplasm effectively and efficiently but also to investigate the genetic mechanisms underlying these responses.

Almost without exception, previous research on the photothermal effects of phenological events in grain legumes has focused on the timing of those events, usually expressed relative to sowing or emergence. But relations between temperature and developmental processes in plants (e.g., germination of seeds, extension of stems, and expansion of leaves) are often simply and precisely described in terms of rate parameters, i.e., the reciprocals of the times taken to particular events (Monteith 1977). This fact prompted us to reexamine both our own and other data on photothermal effects on development in terms of rates of progress toward flowering (1 /f) in different regimes rather than time (days) to flowering (f). The outcome of this exercise involving diverse genotypes of soybean, cowpea, chickpea, and lentil (Hadley, Roberts, et al. 1983, 1984; Summerfield, Muehlbauer, and Roberts, 1984; Roberts, et al. 1985; Summerfield and Roberts et al. 1985; Summerfield and Roberts 1985c) and reevaluation of previously published data on pea, common bean, and mung bean (Hadley, Summerfield, and Roberts 1983) was both dramatic and exciting. It revealed that in all cases, involving both short- and long-day species, the rate of progress toward flowering is a simple linear function of temperature, photoperiod, or both.

With chickpea, the last 50 years have witnessed many investigations on effects of either photoperiod or vernalization on time to flowering; only rarely were both factors considered together using appropriately designed experiments, and the consequences of postvernalization temperature effects received little attention (Summerfield et al. 1980). Realizing these serious limitations, we investigated the effects of factorial combinations of day and night temperature and photopenod on a total of 15 diverse genotypes, again concentrating on days to flowering (Roberts et al. 1980; Summerfield et al. 1981). Differences in photoperiod and in mean diurnal temperature had large effects on time to flowering (longer days and warmer temperatures over the respective ranges of 11 to 15 h and 14.5° to 24.5°C were most inductive and vice versa), and warmer temperatures (>30° C) hastened senescence, curtailed crop longevity, and reduced yield (Summerfield et al. 1984). Nevertheless, a coherent quantitative description of the flowering data did not emerge. Subsequent experiments (Roberts et al. 1985) and more precise analysis of photothermal response data, however, suggest not only a simple model for chickpea flowering in different regimes but also a simple screening technique for separate quantification of temperature and photoperiodic responses.

Factorial combinations of two photoperiods (12 and 15 h), three day temperatures (20,25, and 30°C) and three night temperatures (10, 15, and 20°C), which combined to give eighteen different mean diurnal temperatures between 14.2° and 25.4° C, were imposed on nodule-dependent plants of nine genotypes grown in pots in growth cabinets. The genotypes included both desi (5) and kabuli (4) types classified by field observations at ICRISAT as of "short duration,'' "medium duration," or "long duration." Further, a trio of thermal regimes was duplicated, except that radiation flux density was manipulated so that plants grown in a 15-h photoperiod received the same radiation integral as those in a 12-h photoperiod. Thus, the 189 "treatment combinations" represented an extremely diverse range of both genotypic and environmental variation. For all genotypes in every regime, the times (days from sowing) to first appearance of open flowers were recorded, as were numbers of nodes (main stem plus side branches) below the ones subtending the first flowers.

The principal findings of this investigation are described in detail elsewhere (Roberts et al. 1985) but summarized briefly here:

1. All genotypes were sensitive to photoperiod so that, for any given thermal regime, flowers appeared sooner in the 15-h than in the 12-h photoperiod.
2. Genotypes classified as early maturing in the field were, in general, less sensitive to photoperiod than later-maturing ones.
3. Eight of the nine genotypes tested were sensitive to temperature (and then to mean diurnal temperature rather than to day or night temperature per se) so that, in either photoperiod regime, flowers appeared sooner at the warmest mean temperature.
4. The responses of desi and kabuli genotypes to photothermal regime did not differ in any systematic manner (but the two types were not equally represented in each maturity class, thus precluding a strictly valid comparison of their collective response).
5. Rates of progress toward flowering (1/f) were linear functions of mean temperature (t) and there were no interactions between photoperiod and mean temperature.
6. Photothermal effects were independent of radiation integral (the product of irradiance and photoperiod) and the vegetative stature of the plants.
7. Taken in conjunction with data for lentils, the only other long-day grain legume in which flowering response has been thoroughly investigated with respect to both temperature and photoperiod (Summerfield, Roberts et al. 1985), we suggest that the photothermal response of flowering in chickpea, over the range of environments normally experienced by the crop, can be described by the equation:

$$1/f = a + bt + cp \qquad (1)$$

   where f is the number of days from sowing to first flower, t is mean diurnal temperature, p is photoperiod, and a, b, and c are constants which vary between genotypes.
8. We have no evidence of a critical photoperiod over the range 12 to 15 h for chickpea (or 10 to 16 h for lentil). Thus, in both cases, we believe that the smooth relation indicated by equation 1 probably applies under the range of natural conditions where chickpea (and lentil) crops are grown.
9. The constants a, b, and c in equation 1 provide a basis for screening genotypes for sensitivity to photoperiod and temperature, as we discuss later.

The responses of these diverse genotypes are illustrated in Figure 4 and summarized in Table 4.

The base temperature for flowering (t_0)—i.e., the temperature which is, in theory, sufficiently cool to prevent any progress toward flowering (and so 1/f 0 or f = infinity)—can be calculated by algebraic manipulation of equation 1 to give:

$$t_0 = (-a-cp)/\ b \qquad (2)$$

Thus, the base temperature varies with photoperiod and, therefore, has no obvious agronomic significance. This is in contrast to cowpea and soybean where progress toward flowering is controlled by mean temperature in photoperiod-insensitive genotypes or in photoperiod-sensitive genotypes where photoperiods are shorter than the critical value. Here, the base temperature is unaffected by photoperiod and is a meaningful agronomic value.

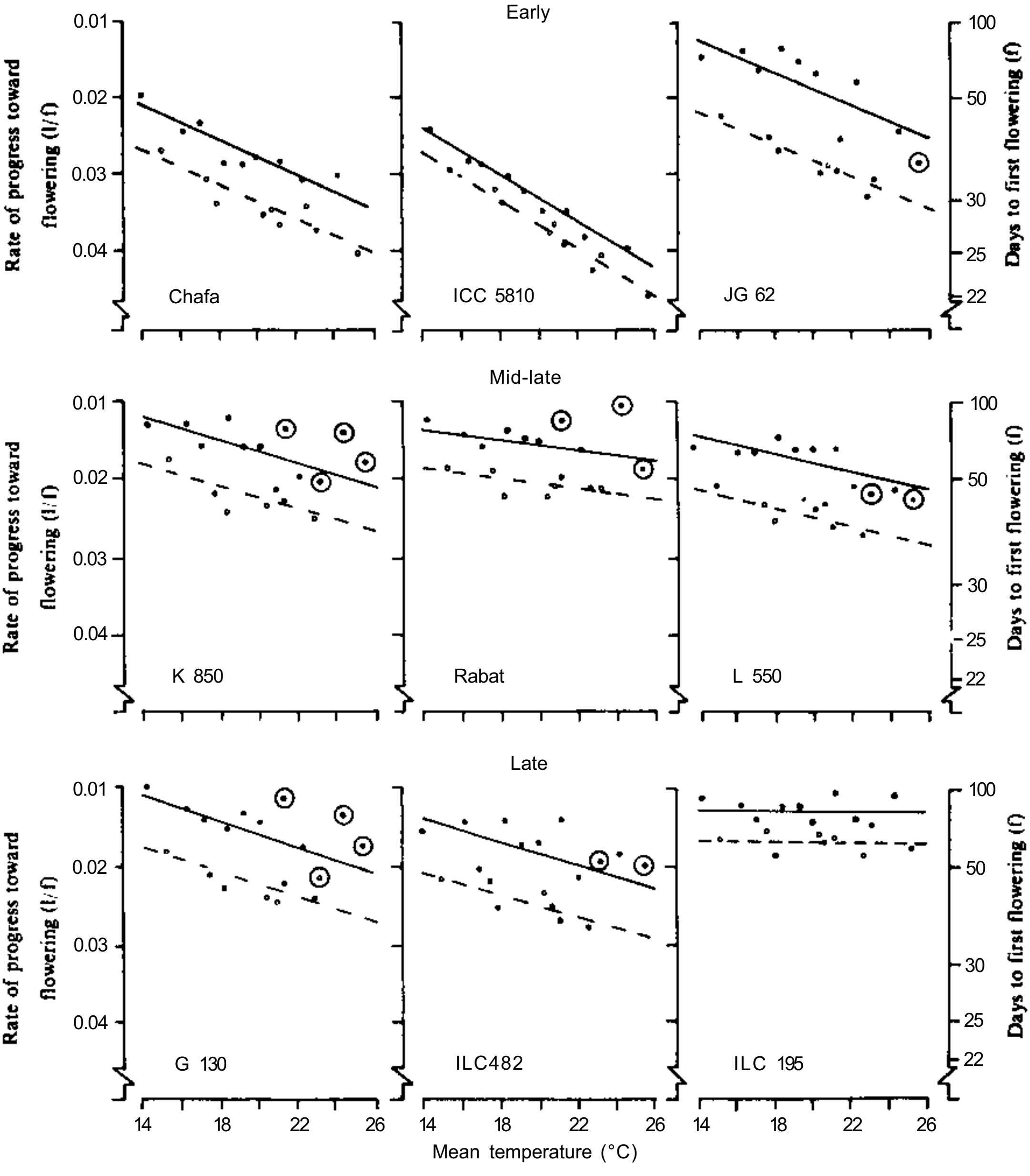

Figure 4. Effects of mean temperature (t=° C) and photoperiod (p=h) on rates of progress toward flowering (1/f, and days from sowing to flowering (f) in nine chickpea genotypes. Symbols denote the experimental mean values in each of 18 environments, 9 in 12-h days and 9 in 15-h days. Fitted regression lines are as described by equation 1. Encircled symbols denote that plants showed an aberrant response in these photothermal combinations (see text) and that these values were not incorporated in the fitting of the regressions.

Table 4. Response characteristics of photothermal effects on flowering in nine chickpea genotypes.

Genotype[1]	Values of constants in equation 1[2]			Proportions of variations in 1/f explained by equation I (r^2)
	a	b	c	
Chafa (d;e)	0.01775	0.0011258	0.001909	86.7
ICC 5810 (d;e)	0.00965	0.0015785	0.000946	95.2
JG 62 (d;e)	-0.04043	0.0010832	0.003100	85.9
K 850 (d;ml)	-0.02295	0.0007488	0.002032	74.8
Rabat (k;ml)	-0.01147	0.0003032	0.001734	69.4
L 550 (k;ml)	-0.02123	0.0005809	0.002266	77.7
G 130 (d;1)	-0.02990	0.0008337	0.002401	86.9
ILC 482 (k;1)	-0.01916	0.0006889	0.002001	57.5
ILC 195 (k;1)	-0.00335	0.0	0.001329	58.7

1. Letters in parentheses denote desi (d) or kabuli (k) types classified as "early" (e), "mid-late" (ml) or "late" (1) to mature in the fields at ICRISAT.
2. Equation 1 denotes $1/f = a + bt + cp$ (see text).

The model described by equation 1 is similar to that developed for photoperiod-sensitive genotypes of soybean when these experience photoperiods longer than their critical daylength (Hadley, Roberts, et al. 1984). But, of course, the photoperiod constant (c) for chickpea, a long-day species, assumes a positive sign (long days hastening flowering), whereas in soybean, a short-day species, it is negative (long days delaying flowering).

Atypical Photothermal Effects on Flowering

For some genotypes, environmental combinations that included days at 30°C with nights of 15 or 20° C caused flowering later than predicted by the model described in equation 1. In these regimes (16 of the 189 combinations tested, i.e., 7.4%; see Fig. 4), the first flowers to appear were also at a significantly higher node than expected from the responses of plants in the large majority of photothermal regimes (Roberts et al. 1985). Data from our previous experiments (Roberts et al. 1980) also indicated that flowering is more delayed in some genotypes at a day/night temperature of 30/ 18°C than at 22/ 18°C. Then again, growth (dry-matter production) and symbiotic nitrogen fixation of cv Chafa were also adversely affected by this warmer combination of day and night temperature (Rawsthorne et al. 1984 a, b). Chickpea, it seems, is not well suited to regimes with such high temperatures.

Similar hot temperature delays in flowering (which reversed the dramatic hastening effects of mean temperatures up to a maximum of about 25-30° C) have been recorded in several genotypes of soybean (Summerfield and Roberts 1985c) and in *Stylosanthes guianensis* (Ison and Humphries 1984). With soybean, flower buds were initiated rapidly and became macroscopically visible but then turned chlorotic and did not expand into open flowers. Is there a similar parallel response in chickpea? We cannot exclude the possibility that later-than-predicted flowering in this small minority of treatment combinations was a consequence of the formation of inconspicuous "pseudo-flowers" before the first perfect flowers opened—i.e., that hot temperature hindered the expansion of initiated buds rather than the floral initiation itself.

Screening Germplasm for Photothermal Responsiveness

The values of the constants b and c in equation 1 can provide a measure of the responsiveness of genotypes to temperature and photoperiod, respectively. The genotypes tested here also differed appreciably in relative earliness (time taken to flower in the most inductive photothermal regime). Thus, since these constants relate to rates (i.e., reciprocals of durations) they must be used with caution when classifying genotypes into response groups according to their relative sensitivity to environmental factors.

For example, an early-flowering genotype with a relatively large b value may respond less in terms of change in number of days to flower per degree increase in temperature than a later flowering genotype with a relatively small b value. This is because a unit change in 1 / f gives a much greater change in f, the larger the initial f value. A similar argument applies to photoperiod sensitivity. The simplest way of overcoming this difficulty is to evaluate equation 1 for each genotype over specific values of p and t. This has been done in Table 5, using the extremes of temperature and photoperiod involved in this experiment; it serves to illustrate that genotypes do not necessarily have the same ranking with respect to either their lateness or relative sensitivity to temperature and/or photoperiod over a range of photothermal conditions.

Genotypes that are more or less sensitive to photoperiod are likely to be well adapted to relatively few environments, whereas genotypes sensitive to temperature are usually well adapted to a wide range of environments. Since the position of the photoperiod-temperature response surface in chickpea is a single plane defined by both temperature and photoperiod (equation 1), the minimum number of environments required to establish it is three (providing these include two photoperiods and two temperatures). Data obtained from this trio of environments would establish the magnitude of both the photoperiodic and temperature responses as well as the relative earliness, or otherwise, of the genotypes tested. As neither traditional chickpea crops nor those which may be cultivated in novel situations (regions and seasons) in the future are likely to experience photoperiods far outside the range used here during the vegetative period (e.g., Table 1), it seems appropriate to use photoperiods of 11 (or 12) h and 15 (or 16) h and a combination of day and night temperatures which will give a mean temperature of 15 or 23° C without using day temperatures warmer than 25° C. An additional temperature combination (e.g., 30°C day/20°C night) could, of course, be included (i.e., a total of four regimes) to screen genotypes for their flowering responses to supraoptimal temperatures. A prudent selection of field sites and, perhaps, use of a glasshouse with precise and reliable control of both photoperiod and temperature (as in Summerfield et al. 1979) might well prove a suitable strategy.

It is clear that chickpea genotypes can be responsive to vernalization and will flower sooner when the requirement for cold has been satisfied (Summerfield et al. 1980). We hope soon to quantify the relations between vernalization and subsequent photothermal effects on development so that the potential usefulness of the model described by equation 1 can be extended. In the interim, this equation and our conclusions for screening based on it could, we believe, be exploited to considerable advantage by chickpea breeders. Indeed, since we have no evidence for a correlation between relative sensitivity to temperature and relative sensitivity to photoperiod,

Table 5. Days to first flower at a mean temperature of 14° and 26° C, combined with a photoperiod of 12 or 15 h (calculated from Equation 1), and ranking according to earliness and sensitivity to photothermal regime in nine chickpea genotypes.

					Ranking of relative sensitivity to temperature and photoperiod[1]			
	Duration of vegetative period (days)				Sensitivity to temperature		Sensitivity to photoperiod	
Genotype	14°C/12 h	26°C/12 h	14°C/15 h	26°C/15 h	12 h	15 h	14°C	26° C
Chafa	47.8 (2)[2]	29.0 (2)	37.5(1)	24.9 (2)	4	4	2	2
ICC 5810	42.0(1)	23.4(1)	37.5(1)	22.0(1)	3	6	1	1
JG 62	83.8 (7)	40.1 (3)	47.1 (3)	29.2 (3)	8	7	8	5
K 850	84.0 (8)	47.8 (6)	55.5 (7)	37.0 (7)	7	8	7	4
Rabat	73.6 (5)	58.1 (8)	53.2 (6)	44.6 (8)	2	2	5	8
L 550	71.0(4)	47.5 (5)	47.9 (4)	35.9 (5)	5	3	6	6
G 130	94.5 (9)	48.6 (7)	56.2 (8)	36.0 (6)	9	9	9	7
ILC 482	69.0 (3)	43.9 (4)	48.8 (5)	34.8 (4)	6	5	4	3
ILC 195	79.4 (6)	79.4 (9)	60.3 (9)	60.3 (9)	1	1	3	9

1. Sensitivity ranked according to number of days alteration in days to first flowering due to the environmental factor considered.
2. Figures in parentheses indicate ranking according to earliness.

nor of any interaction between temperature and photoperiod, it seems that while responsiveness to these two factors affects the same phenological event (i.e., time to flowering) they are under separate genetic control.

Simulations that relate biological knowledge about recognizable and unambiguous phases of plant development to environmental factors, and mimic field behavior, are likely to be the most useful; when they are reliable and accurate, such models might be expected to transform weather parameters into phenological statistics (Waggoner 1974). The full exploitation of transformations that relate flowering behavior to photothermal conditions in grain legume crops in general, and chickpea in particular, now depends on perspectives and priorities in different crop improvement programs.

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Water Stress

Chairman : J.M. Peacock
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Management of Chickpea and Pigeonpea under Stress Conditions, with Particular Reference to Drought

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Abstract

Management practices designed to increase the productivity of rainfed chickpea and pigeonpea, and ways to alleviate the ill effects of drought, are highlighted in this paper. These practices are based on experience gained in the All India Coordinated Research Project for Dryland Agriculture. Discussed herein are suitable crop varieties, cropping systems, timely sowing, optimum seed rate, fertilizer use, supplemental irrigation, and other technology components that contribute to increasing and stabilizing the production of chickpea and pigeonpea.

Chickpea-based cropping systems are very popular with dryland farmers. In medium and deep black soils, intercropping chickpea with safflower offers promise. The productivity of chickpea is directly associated with the moisture-storage capacity of the soil and the amount of winter rain received during the cropping season. In black soil regions, the limited moisture stored in the soil is better utilized by timely sowing (first half of October to mid-November). Chickpea yield is not influenced by seed rates between 30 and 60 kg ha^{-1}. A plant population of 185 000 ha^{-1} is about optimum. In soils with low phosphorus, chickpea responds very well to applied phosphorus, which also increases water-use efficiency (WUE). In the range of 110-240 mm water use, yield increases linearly, producing 13.5 kg seed per mm of water use. In light-textured soils, fertilizer application at 10-cm depth before presowing irrigation (5 cm) significantly increases chickpea yield. In soils with low phosphorus, nutrient stress is more dominant than moisture deficits.

Sorghumlpigeonpea intercropping has been found productive, stable, and remunerative for most sorghum-growing areas. Genotypic interactions have been established among components studied in the sorghum/pigeonpea intercropping system. Plant density plays an important role in pigeonpea productivity, particularly on Alfisols. Optimal populations depend on the duration of the pigeonpea variety. Staggered planting is efficient in ensuring good crop establishment and growth. Nutrient management also assumes importance in intercropping. One or two supplemental irrigations, depending on soil type, are required for realizing good pigeonpea yields. Postrainy-season pigeonpea has not yet received due agronomic research attention.

Introduction

Chickpea and pigeonpea are the two most important pulse crops grown in India. Chickpea accounted for 42% and pigeonpea for 18% of the total pulse production (22.6 million t) during 1980/ 81. In that year, chickpea occupied 6.7 million ha and pigeonpea 2.8 million ha, with an average productivity of 690 kg ha^{-1} for chickpea and 720 kg ha^{-1} for pigeonpea.

Only 40 g head^{-1} day^{-1} of pulses is now estimatedly available to the Indian population, as against the 104 g recommended for consumption by the World Health Organization (Lal 1984). To meet the requirements of pulses, the National Commission on Agriculture (1976, pp. 87-88) laid more emphasis on increasing crop productivity than on expanding the cropping area. Productivity for 2000 AD has been targeted at 1500 kg ha^{-1} for both chickpea and

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pigeonpea. From yields obtained at research stations, the present yield realization of chickpea is only about 30% of the potential. In the case of pigeonpea, it is 45% (Balasubramanian 1983). These yield gaps need to be bridged in farmers' fields if the production targets are to be reached.

The management aspects of these crops under rainfed conditions are highlighted in this paper. The data presented are mostly from unpublished reports of work conducted by the All India Coordinated Research Project for Dryland Agriculture (AICRPDA).

Chickpea

Chickpea is grown extensively in the postrainy season, with about 85% of the area under it rainfed. The major chickpea-growing states of India are presented in Table 1. Chickpea cultivation is evidently concentrated more in northern and central than in southern India, because of longer and more favorable growing seasons there with cooler temperatures and better moisture regimes. In southern India, despite low productivity, chickpea is grown to meet farmers' domestic requirements. Suitable varieties of chickpea are now available for different environmental conditions. Some of the more promising varieties are listed in Table 2.

Table 1. Area and productivity of chickpea in major chickpea-growing states of India (After Fertilizer Association of India 1983).

State	Area ('000 ha) 1980-81	Productivity (kg ha-') 1980-81	Rainfed area (%) 1978-79
Andhra Pradesh	51.1	258	-
Bihar	186.0	753	95.9
Gujarat	63.5	740	87.9
Haryana	720.0	903	74.4
Karnataka	152.0	566	94.5
Madhya Pradesh	1945.6	579	92.9
Maharashtra	429.1	350	86.7
Orissa	52.0	513	-
Punjab	268.0	746	76.4
Rajasthan	1227.0	696	82.5
Uttar Pradesh	1493.4	860	80.7
West Bengal	96.2	578	-
All India	6683.9	628.5	84.6

Source: Fertilizer Statistics 1982-83: Table 2.07, Page 11. 34; Table 1.07 Page 11, 14.

Chickpea-Based Cropping Systems

Chickpea is grown extensively as a sole crop. In the black soil regions of southern India, the crop is raised on stored soil moisture. In northern India, the crop gets the benefit of winter rains, besides stored

Table 2. Performance of chickpea as influenced by rainfall and growth duration (Adapted from AICRPDA 1983).

Region	Mean annual rainfall (mm)	Moisture storage (mm m^{-1})	Variety	Growth duration (days)	Yield potential (t ha^{-1})
Black Soils					
Bellary	500	160 300	A-1, N-52	76	0.5-0.6
Bijapur	680	160-300	A-1	90-95	0.6-0.7
Sholapur	722	160 300	Chafa, N-59	85-95	0.6-0.7
Indore	990	300	Ujjain-21, -24	110-125	1.5 2.0
Jhansi	930	160-300	BG-200, 208	155-160	1.7 1.8
Udaipur	635	160-300	C-235, Dohad, BG-203	120-155	1.5-2.2
Submontane Soils					
Hoshiarpur	1000	90-100	C-235	130-140	1.0-1.2
Rakh Dhiansar	1180	110-140	C-235	135	1.0
Sierozemic Soils					
Hisar	400	90-110	H-208, C-214, -235	140-175	2.2-2.4
Alluvial Soils					
Agra	710	140-180	G-24, -130	155-160	2.1-2.4
Varanasi	1080	140-180	BG-1,-2, T-1,-3, -6	149-156	3.0-3.5

soil moisture. Productivity of chickpea is directly associated with the moisture-storage capacity of the soil, as evident from Table 3.

The water requirement of chickpea varies from 204 to 280 mm (Sharma et al. 1974). The available moisture in black soils ranges from 135 to 300 mm m^{-1} depth during the growing season (23 weeks) depending on soil depth, which can hardly sustain a good sole crop of chickpea. Obviously, intercropping of chickpea under such situations was not successful with coriander at Bellary or with safflower at Sholapur and Bijapur (Chetty 1983). The land equivalent ratio (LER) of an intercropping system seldom exceeded 1.0. However, in good rainfall years (1979/80 and 1981/82) at Bijapur, intercropping of chickpea with safflower proved successful, as shown in Table 4.

The practice of intercropping chickpea with safflower in a 3:1 row ratio is recommended for medium to deep black soils, although chickpea productivity is low. However, if the LER does not fall below 1.0, it is acceptable to farmers. Other promising chickpea-based intercropping and mixed cropping systems include chickpea and mustard for alluvial soils of the Agra and Jammu regions, and chickpea and wheat for submontane soils of the Ludhiana region.

The performance of chickpea and other postrainy-season crops was evaluated at Hisar under different moisture regimes. Chickpea yield was found on par with that of mustard and taramira (*Eruca sativa.* Table 5).

Chickpea ranks high in crop sequences followed on drylands in northern and central India. Chickpea-based crop sequences are popular with farmers on two counts: (1) they are more remunera-

Table 3. Influence of soil depth and available soil moisture on seed yield of chickpea, Sholapur (average of 3 years, 1975/76 to 1977/78). Source: AICRPDA Annual Reports and Mahatma Phule Krishi Vidyapeeth, Sholapur, Maharashtra, India.

Soil type	Soil depth (cm)	Available moisure-capacity capacity (mm)	Seed yield (kg ha^{-1})
Shallow	0-30	37	430
Medium	0-60	87	560
Deep	0-90	140	830

Table 5. Comparative performance of chickpea, mustard, and taramira (*Eruca sativa*) under different soil moisture conditions at Hisar (AICRPDA Annual Reports and Haryana Agricultural University, Hisar, Haryana, India).

Soil moisture storage capacity (mm)	Seed yield (kg ha^{-1})		
	Chickpea	Mustard	Taramira
152	660	800	890
177	720	1170	980
227	1430	1170	890
277[1]	1290	1260	1030
327[2]	1550	1350	1260

1. One 5-cm irrigation, during December.
2. Two irrigations, 5 cm each, during December and January.

Table 4. Seed yield and land equivalent ratio (LER) as influenced by chickpea/safflower intercropping at Bijapur (AICRPDA Annual Report and University of Agricultural Sciences, Bijapur).

	Rainfall (mm)					
Season	Rainy season (4 Jun to 30 Sep)	Post rainy season (1 Oct to 2 Dec)	Winter (3 Dec to 4 Mar)	Cropping system	Seed yield (kg ha^{-1})	LER
1979/80	485.3	251.6	0	Chickpea (sole)	1480	1.00
				Safflower (sole)	1630	1.00
				Chickpea/ safflower (2:1)	600/ 1510	1.34
1981/82	608.0	61.0	0	Chickpea (sole)	1110	1.00
				Safflower (sole)	1410	1.00
				Chickpea/ safflower (2:1)	960/ 850	1.47

tive than wheat- or barley-based cropping systems; (2) chickpea is able to extract moisture more efficiently from deeper layers of the soil than cereal crops, and it can thus withstand drought much better. Three conditions seem to be essential for the success of chickpea-based crop sequence systems: (1) adequate soil moisture (about 200 mm m^{-1} of the soil) at the time of sowing; (2) winter rains about 60-80 mm; (3) optimum temperatures at sowing (about 25°C) and during crop growth. It is desirable that short-duration varieties of maize, upland paddy, sorghum, etc., precede chickpea to leave more residual moisture and to give adequate time for field preparation. Upland paddy-chickpea at Varanasi and Rewa, and maize-chickpea at Ludhiana and Dehradun, proved more stable, productive, and remunerative than other systems tried (Table 6). The sorghum-chickpea sequence is more common in southern India. Sorghum, however, does not leave enough moisture for a good harvest of chickpea.

Stability in Chickpea Production

When compared to other postrainy-season crops, chickpea is better adapted to drought stress situations, as illustrated by its stable performance over the years at Hisar (Table 7), where the overall productivity of chickpea was higher than that of mustard and safflower.

The seed yield of chickpea was found to be more closely correlated with rainfall received during the monsoon and winter seasons than the seed yields of mustard and safflower (Table 8). The productivity of chickpea could, therefore, be predicted from the stored moisture at sowing plus anticipated winter rains. However, temperatures and evaporative demand during the growing season should also be taken into account.

Counteracting Drought Effects

Since chickpea is sown on stored soil moisture, there is every likelihood that the crop may face short spells of drought during the growing season, if the moisture at sowing time is inadequate or if winter rains fail. Some agronomic practices are known to help mitigate the adverse effects of drought and these are discussed below.

Timely sowing. Timely sowing, especially in black

Table 6. Total productivity and monetary returns in some sequential cropping systems (AICRPDA Annual Reports for respective locations). Data averaged as follows: Rewa, 4 years (1972-75); Varanasi 3 years (1972-74); Dehradun 8 years (1972-79).

Region	Soil type	Moisture storage (mm m^{-1})	Winter rains (3 Dec to 4 Mar) (mm)	Cropping systems		Total productivity (kg ha^{-1})	Monetary returns (Rs ha^{-1})[1]
				1st crop	2nd crop		
Rewa	Black	270 300	36.3	Fallow	Chickpea	740	1480
				Upland paddy	Chickpea	1920	2517
				Upland paddy	Wheat	1790	1824
Varanasi	Alluvial	140 180	42.7	Fallow	Chickpea	3590	7180
				Upland paddy	Chickpea	5560	7949
				Upland paddy	Wheat	5180	5353
Dehradun	Submontane	140-180	88.2	Maize	Wheat	7280	7124
				Maize	Barley	6730	5867
				Maize	Chickpea	5430	6490

1. Price of produce (Rs per 100 kg): maize = 85, upland paddy = 95, barley = 90, chickpea = 200, and wheat = 115.

Table 7. Performance of postrainy-season crops as affected by amount and distribution of rainfall, Hisar (AICRPDA Annual Reports and Haryana Agricultural University, Hisar, Haryana, India).

	Rainfall (mm)			Seed yield (kg ha^{-1})		
Year	Rainy season (4 Jun to 30 Sep)	Postrainy season (1 Oct to 2 Dec)	Winter (3 Dec to 4 Mar)	Chickpea (C-235)	Mustard (RH-30)	Safflower (EC-27250)
1972/73	227.3	51.2	32.6	2530	-	2240
1973/74	193.5	3.8	12.3	2010	-	1560
1974/75	168.4	1.8	4.5	1410	1560	1500
1975/76	295.1	21.6	14.0	2670	2390	2860
1976/77	531.2	0.0	28.4	2140	2430	1940
1977/78	441.2	0.2	15.7	2930	1120	-
1978/79	434.3	3.0	49.2	3030	2440	2040
1979/80	331.6	0.0	12.5	-	1990	2170
1980/81	149.0	6.8	0.0	2330	2190	2190
Mean	308.0	9.8	18.8	2380	2020	2060

Table 8. Correlation coefficient (r) of rainfall with yield of chickpea, mustard, and safflower (M. Narayana Reddy, AICRPDA, Hyderabad 500 659, A.P., India, unpublished data).

Crop	Rainy season[1]	Postrainy season[2]	Winter[3]
Chickpea (C-235)	0.503	0.189	0.560
Mustard (RH-30)	0.131	0.401	0.424
Safflower (EC-27250)	0.157	0.457	0.102

1. Average rainfall, 308.8 mm.
2. Average rainfall, 9.8 mm.
3. Average rainfall. 18.8 mm.

Table 9. Effect of sowing time on seed yield of chickpea at Hisar[1] (AICRPDA Annual Reports and Haryana Agricultural University, Hisar, Haryana, India).

	Seed yield (kg ha^{-1})	
Sowing time	1975/76	1976/77
Fourth week of September	1400	2380
Mid-October	1440	2380
Fourth week of October	1040	1910
Mid-November	850	1280
CD (0.05)	415	221

1. Rainfall (mm) in the rainy, postrainy, and winter periods was 295, 22, and 14, respectively, in 1975/76 and 531.0. and 28 in 1976/77.

soils, permits better use of the moisture stored in the soil. Advancing the sowing date of chickpea in these regions can allow better moisture use. It was demonstrated at Bellary that in dry years sowings have to be done early in the season, while in good years sowing date can be more flexible. In northern and northwestern India (e.g., Hisar and Jammu), the optimum sowing time for chickpea was found to be the first half of October, and any delay beyond mid-October resulted in lower yields (Table 9). At Rewa, sowings could be done up to November without significant reduction in yield. In general, mid-October to mid-November is the ideal time for sowing chickpea (Saxena 1979).

Optimum seeding rate. Optimum seeding rates are extremely important when crops are grown under stress situations; they help avoid unnecessary competition for the limited amount of moisture available in the soil and for nutrients. At Hisar, seed rates from 30 to 60 kg ha^{-1} did not cause any significant differences in yield. Similarly, at Bellary it was shown that chickpea yield did not increase beyond a plant population of 185 000 plants ha^{-1}. Instead, yield decreased when the plant population was increased to 254 000 and 310 000 plants ha^{-1}, despite a rainfall of 457 mm.

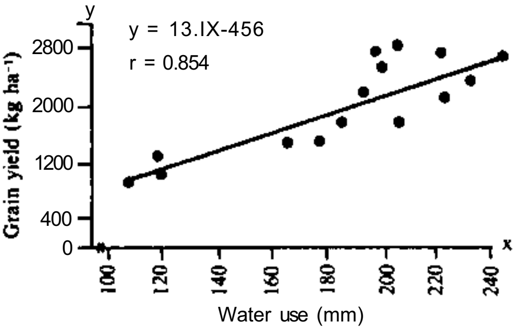

Figure 1. Effect of water use on grain yield of chickpea, Dehradun.

Fertilizer use. The response of chickpea to applied fertilizers was reviewed earlier (Saxena 1980). In essence, it emerged that: (1) a starter dose of N at 15-25 kg ha^{-1} is useful for enhancing chickpea yield; (2) response to applied P in black soils is inconsistent, and often absent, because the soil has a high phosphorus-fixing capacity, but chickpea can still extract some P, normally unavailable, from the soil; (3) in other soils, response to applied P was observed when the available P content was low. Research conducted at different dryland research locations in India also confirms these observations.

Singh et al. (1981) reported that application of phosphorus increased seed yield and water-use efficiency (WUE) of chickpea at Dehradun (Table 10). Maximum chickpea yield (2530 kg ha^{-1}), about 78% higher than the control, was obtained with 32 kg ha^{-1} applied P. The WUE was also found to progressively increase with P application up to 32 kg ha^{-1}. The correlation coefficient between water use and chickpea yield was found to be significant, as shown in Figure 1. The regression equation obtained suggested that, in the range of 110-240 mm water use, yield increased linearly, producing 13.5 kg seed per mm of water used.

Saxena and Sheldrake (1976, p. 176) did not find any beneficial effect of deep placement and advance application of phosphorus in a black soil due to the high phosphorus-fixing capacity of the soil. However, at Hisar it was shown in 1982/83 that application of fertilizer either broadcast or placed at 10 cm depth before presowing irrigation (5 cm) increased chickpea yield by 25%.

Supplemental irrigation. Although chickpea is grown primarily as a rainfed crop, its water requirement is often not met from the stored moisture in the soil and the rainfall received during the crop growth period. A favorable response to supplemental irrigation has been reported (IARI 1977, pp. 211-215; Singh 1983). Recent work at Hisar demonstrated that applying 15 cm water at the presowing stage (when soil moisture before irrigation was 62 mm m^{-1} depth) enhanced chickpea yield substantially. At Dehradun, supplemental irrigation of 5 cm given at both the presowing and flowering stages significantly increased chickpea yield over the control by 36% (Table 11).

Technology Components

Studies at Hisar to determine the effect of different components of technology recommended for chick-

Table 10. Effect of phosphorus application on the yield and water-use efficiency (WUE) of chickpea, at Dehradun (mean of 3 years, 1972/73 to 1974/75) (Singh et al. 1981).

P levels (kg ha^{-1})	Seed yield (kg ha^{-1})	Water use (mm)	WUE (kg grain mm^{-1} ha^{-1})
0	1420	166	8.5
11	1830	179	10.2
22	2110	182	11.5
32	2530	210	12.0
44	2370	195	12.2
CD (0.05)	359	-	-

Table 11. Seed yield of chickpea as affected by time of applying irrigation, at Dehradun(mean of 2 years, 1977/78 and 1978/79) (Singh et al. 1981).

Irrigation treatment	Seed yield (kg ha^{-1})	Increase in yield over control (%)
Control (no irrigation)	1460	-
Presowing irrigation (5 cm)	1710	18
One presowing irrigation (5 cm) + one at 45 days of crop growth (5 cm)	1740	19
One presowing irrigation (5 cm) + one irrigation at flowering stage (5 cm)	1980	36

pea showed that use of improved seed, fertilizer, and plant protection are the major technology components enhancing chickpea yield. As the maximum yield increase obtained was only 16% and as the effect of supplemental irrigation was not investigated, further studies are needed to quantify the relative contribution of technology components to yield improvement.

Scope for Increasing Dryland Chickpea Production

As the scope for increasing the area under chickpea is limited (National Commission on Agriculture 1976, pp. 87-88), productivity has to be increased. In southern India, where chickpea is grown on black soils, it suffers from the unfavorable moisture conditions of warm winters. Until early-maturing (about 90 100 days) and high-yielding genotypes are made available, the prospects for chickpea are limited in this region. It may even be replaced by other remunerative crops, such as safflower and coriander. Chickpea will continue to be used in sorghum-chickpea cropping systems, however, for want of a better alternative. Chickpea yields can be raised in the black soil region through judicious fertilizer use and better disease and pest control. In Madhya Pradesh, where the crop environment is more favorable, providing at least one supplemental irrigation can help increase chickpea yields substantially.

Greater prospects for realizing higher chickpea productivity lie in the northern and eastern regions of the country, where assured winter precipitation promises a good harvest, provided fertilizer (particularly P) is not limiting and pod borer damage is controlled. Access to one or two supplemental irrigations will also help.

Pigeonpea

Pigeonpea ranks next to chickpea in India in terms of area and production. The major states growing pigeonpea, with areas sown and productivity, are given in Table 12.

Table 12. Area and productivity of pigeonpea in major pigeonpea growing states of India, 1980/81 (Fertilizer Association of India 1983).

State	Area ('000 ha)	Productivity (kg ha-')
Andhra Pradesh	226.4	195
Bihar	86.0	1163
Gujarat	187.8	754
Karnataka	310.4	644
Madhya Pradesh	514.9	560
Maharashtra	706.1	510
Orissa	88.5	492
Tamil Nadu	71.1	560
Uttar Pradesh	523.4	1411
All India	2810.7	717

As a rainy-season crop, pigeonpea is grown mainly on black, alluvial, and red soils of India. About 90% of the area under this crop is rainfed. Further, it is grown mostly as a mixed crop or intercrop. The AICRPDA has directed its research to intercropping aspects in those regions and soil types where sequential cropping is not feasible; these are areas receiving an annual rainfall of 625-800 mm and soils having a moisture-storage capacity of about 20 cm m^{-1} soil depth.

Cropping Systems

Results obtained by AICRPDA have shown that pigeonpea can be grown as an intercrop with cereals, other pulses, or oilseeds. However, cereal/ pigeonpea intercropping systems are more widely accepted in India. Sorghum, pearl millet, finger millet, maize, and upland rice are the main cereal components. The sorghum/pigeonpea intercrop system is prevalent in medium- to heavy-textured soils of southeastern Uttar Pradesh, Bundelkhand, and Malwa; the Vidharba and Marathwada regions of Maharashtra; northern Karnataka; and the Telangana and Rayalaseema regions of Andhra Pradesh. Pearl millet/ pigeonpea intercrop systems are quite common on light-textured soils of western Uttar Pradesh, the Saurashtra region of Gujarat, northern Karnataka, the Deccan region of Karnataka, and the Vidharba region of Maharashtra. Maize/pigeonpea intercrop systems find a place in southeastern Rajasthan and the Bihar plateau, whereas upland rice/ pigeonpea systems are practiced in eastern Uttar Pradesh, the Bihar plateau, and parts of Orissa.

In the pulse/pigeonpea intercrop systems, short-duration (60-70 days) pulse crops like greengram, blackgram, and cowpea are ideal as they give an extra yield of 400-500 kg ha^{-1},without lowering the pigeonpea yield. The pigeonpea/greengram intercrop occupies major areas in Punjab, Haryana, western Uttar Pradesh, Gujarat, Tamil Nadu, and

Maharashtra, whereas pigeon pea/ blackgram is preferred in Madhya Pradesh, Andhra Pradesh, and Bihar. Pigeonpea/cowpea intercropping system are limited only to some areas of Karnataka.

The most common oilseed crops intercropped with pigeonpea are groundnut and soybean. Groundnut/pigeonpea intercropping systems are suited to the states of Maharashtra, Andhra Pradesh, Karnataka, and Gujarat. Soybean/ pigeonpea intercropping system has been introduced with success in the Malwa and Bundelkhand regions.

Pigeonpea/soybean intercropping in a 1:1 row ratio has been found not only remunerative but also highly productive in terms of energy output (Table 13). Energy output per hectare from this cropping system is much higher than in other cropping systems, as reported earlier by Singh and Chetty (1981); however, it ranks about equal with a maize/ soybean system, which produces about 50 MJ ha^{-1}.

Suitability of Genotype

The overriding considerations in intercropping systems have been (1) better exploitation of natural resources, thereby increasing productivity from unit land per unit time, and (2) better stability in production. The initial slow growth rate of pigeonpea and its deep rooting character make it eminently suitable as an intercrop that does not adversely affect the yield of its companion crop. In such cases, selection of suitable varieties, which match the growing season of the area concerned, is important. The particulars of some pigeonpea varieties with growth patterns suited to various regions in India are given in Table 14.

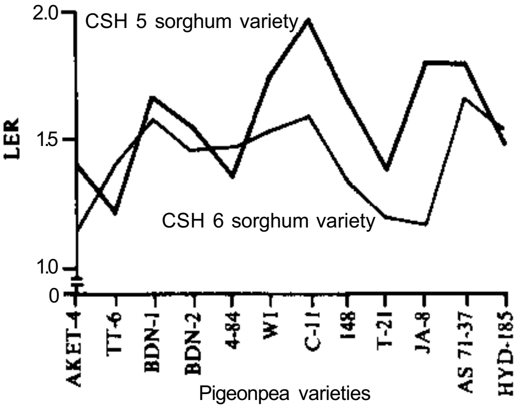

Figure 2. Varietal influence on land-equivalence ratio (LER) in soybean/pigeonpea intercropping systems, Akola.

With the availability of genotypes having short (about 130 days), medium (about 150 days), and long (about 180 days) duration, AICRPDA is trying to identify suitable and compatible genotypes of both the component crops for different pigeonpea-based intercropping systems. Initial trials at different locations showed genotypic interactions among the components of the intercropping system. For example, results obtained at Akola have shown that the C-11 variety of pigeonpea is most compatible with CSH 5 sorghum, whereas AS71 -37 pigeonpea is most suitable for intercropping with CSH 6 sorghum (Fig. 2).

Sowing Time

In pigeonpea, sowing date has a significant influence on yield. Trials conducted at Hyderabad on red soils have shown that sowing of pigeonpea with the onset of rainfall is desirable.

Table 13. Seed yield and energy values from pigeon pea/soybean intercrops at Indore (Singh and Chetty 1981).

	Seed yield (kg ha^{-1})			Gross	
Cropping pattern	Pigeonpea	Soybean	LER[1]	return (Rs ha^{-1})	MJ ha^{-1}
Sole pigeonpea	1890	-	1.00	7290	26.4
Sole soybean	-	2020	1.00	5932	25.4
Pigeonpea/ soybean (1:1 row ratio)	2180	1580	1.93	9191	50.3
Pigeonpea/ soybean (1:2 row ratio)	880	1670	1.28	8303	33.3

1. LER = land equivalence ratio.

Table 14. Length of growing season and particulars of pigeonpea varieties recommended for some dryland areas of India (Adapted from AICRPDA 1983).

Location	Average rainfall (mm)	Soil type	Moisture storage (cm m^{-1})	Growing season	Crop duration (days)	Varieties recom-mended	Duration (days)	Yield potential (kg ha^{-1})
Agra	710	Alluvial	14-18	2 Jul-23 Dec	168	Pusa Ageti	150-160	1100-1200
						T 21	150-160	1400-1500
Varanasi	1080	Alluvial	14-18	25 Jun 16 Dec	168	T21	176	1200-1300
Indore	990	Black	30	10 Jun-18 Nov	154	No. 148	165-170	1300-1600
						Khargone 2	150-155	1200-1500
						Hy4	150-160	1400-1600
Sholapur	722	Black	16-30	16 JuJ-18 Nov	126	No.148	145-155	2100-2200
						T21	115-125	1700-1800
Akola	830	Black	16-30	18 Jun-2Dec	168	C 11	190-200	1200
						T21	135-140	1200
Hyderabad	770	Red	9-15	18 Jun-18 Nov	154	Hy2	150	1200
						Hy4	150	1200

Similar results showing the importance of sowing of rainfed pigeonpea at the onset of the monsoon have been obtained by the All India Coordinated Pulse Improvement Project (AICPIP) at Hisar, Ludhiana, Delhi, Coimbatore, and Pantnagar. Since most pigeonpea genotypes are photoperiod sensitive, late sowing reduces the growing period, which leads to poor pod formation. Further, when sown late the crop is more likely to face moisture deficits in areas where postmonsoon and winter rains are scarce.

Plant Density

Plant density trials conducted on Alfisols at Hyderabad indicated a yield plateau between 50 000 and 100 000 plants ha^{-1}. Elaborate studies made by AICPIP revealed that early genotypes, such as UPAS 120, Pusa 84, H77-216, and T-21, perform well at about 100000 plants ha^{-1}. However, medium-duration varieties, such as BDN-1, BDN-2, C-11, CS 1, and HY 3 C, give optimum yields at about 75 000 plants ha^{-1}. The optimum population for late varieties, like T-17, T-7, Gwalior 3, and Laxmi, which grow tall and form a larger canopy, is 50 000-60 000 plants ha^{-1}.

Staggered Planting

The usefulness of staggered planting in intercropping systems was reported earlier (De and Singh 1981). The staggering in planting time is aimed at avoiding competition between the intercrop components during peak growing periods. Recent studies on Alfisols at Hyderabad showed that pigeonpea yield in an intercropping system with pearl millet can be increased by about 30% if pigeonpea is planted about 15 days earlier than pearl millet (Ravi Prakash 1984). It was also observed that higher LER (1.51) and gross monetary returns were realized in the treatment where 60 000 plants ha^{-1} were maintained by early sowing.

Nutrient Management

The need for applying N and P to pigeonpea has been adequately stressed and results pertaining thereto have been reviewed by Kulkarni and Panwar (1981). Venkateswarlu et al. (1981) also elaborated on the nutrient management aspects of intercropping systems for red soils. Other results obtained by AICRPDA showed that 12-20 kg ha^{-1} N is essential as a starter dose for pigeonpea. Under cereal/pi-

Table 15. Seed yield of pigeonpea as influenced by production factors (Ali 1983).

Production inputs[1]	Seed yield (kg ha-')	Increase over control (%)
f w p (control)	910	-
F w p	1110	22
f W p	1260	38
f w P	1070	17
F Wp	1230	35
F w P	1040	14
f W P	1070	17
F W P	1410	54

1. f = fertilizers, w = weed control, and p = plant protection in the local control; F = 10 kg N ha^{-1} + 17 kg P ha^{-1}, W = Two hand weedings, and P = Two sprays of 0.07% endosulfan, in the improved treatments.

geonpea intercropping systems the amount of nitrogen to be topdressed should be applied to cereals only. Phosphorus at the rate of 12-18 kg ha^{-1} needs to be applied as a basal dressing to both components of the intercropping system. For dryland cropping systems, responses to K and Zn application have not been documented.

Supplemental Irrigation

Pigeonpea is vulnerable to moisture deficits if the monsoon rains cease early. Under such conditions, supplemental irrigation helps raise the productivity of pigeonpea, under both sole and intercrop systems (Vijayalakshmi 1983). Yield responses to irrigation up to 560% at Jhansi and 300% at Hyderabad have been reported. In general, for realizing good yields, one or two irrigations, depending upon soil type, occurrence of postmonsoon and winter rains, and duration of the crop, are required. The black soils, once fully charged with late monsoon rains, may not require supplemental irrigation.

Postrainy-Season Pigeonpea

Pigeonpea sown in the postrainy season is gaining ground in various parts of India, particularly in the eastern regions. However, management practices for rainfed conditions are yet to be developed. Different varieties of pigeonpea grown at Bhubaneswar had yields from 260 to 300 kg ha^{-1}. These are quite low, but further studies on this aspect are required.

Contribution of Production Factors

AICPIP has studied the relative contribution of production factors, fertilizer use, weed management, and plant protection (Ali 1983). As shown in Table 15, weed management is the most important factor in increasing productivity, followed by fertilizer use and plant protection.

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Screening for Adaptation to Drought: Case Studies with Chickpea and Pigeonpea

N.P. Saxena[1]

Abstract

Water deficits account for nearly 50% of the variation in chickpea and pigeonpea production caused by both biotic and abiotic stress factors. Irrigation is not always practicable to alleviate water deficits, and when it is not properly practiced, it may also lead to the negative consequences of waterlogging and salinity. Better management and crop adaptation to drought can improve and stabilize yield in drought environments to some extent, even if they do not entirely help realize the crop's genetic potential. They become essential approaches for areas where irrigation is not feasible. Prospects for adaptation of chickpea to drought in the peninsular Indian environment are encouraging, and they need to be explored further in other environments. The methodology and criteria used for selection need to be more thoroughly evaluated before initiating a breeding program for drought tolerance in this crop. In pigeonpea, very few attempts have been made to screen genotypes for adaptation to drought. The problem is more complex because of difficulties in reproducing the unpredictable and variable moisture environment that the crop experiences. However, pigeonpea is also exposed to terminal water deficits in a manner similar to chickpea, and screening methods developed for chickpea should be applicable to pigeonpea.

Introduction

Extending cultivation of food crops into suboptimum environments, including drought-prone areas, is becoming increasingly important to overcome food deficits in regions of most need. Drought environments are characterized by wide fluctuations in precipitation, in quantity and distribution within and across seasons. These fluctuations are largely responsible for the major famines that have occurred (Swindaleand Bidinger 1981;Lappe et al. 1977). For example, three-quarters of the arable area in India is considered drought prone (Venkateswarlu 1982), as are large areas of the semi-arid tropics in Africa (Lappe et al. 1977).

The gap between genetic yield potential and the yield realized is primarily related to environmental stress factors. In semi-arid environments, crop losses and large reductions in yield are due to water deficit (Simpson 1981). In the United States of America, it is estimated that of the various stress factors—such as diseases, insects, weeds, water deficit, waterlogging, salinity, alkalinity, and low temperature—water availability alone depresses yield by 45% (Boyer 1982).

A simple but effective way of increasing yield in drought environments is to alleviate the water deficit through irrigation. However, injudicious and faulty irrigation may lead to development of salinity and waterlogging; these problems are very expensive to correct and the damage may even be irreversible.

Only 14% of the world's arable area is irrigated at present (Simpson 1981), and prospects for substantial further increases in irrigable area are limited, especially in semi-arid regions. It is thus important to explore other alternatives for increasing and sta-

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bilizing crop yields in drought environments. These include (1) making optimum use of incident rainfall by using appropriate agronomic practices, and (2) breeding for and selection of genotypes better adapted to drought. With the latter approach, productivity can be increased to a level that depends upon the nature and intensity of drought but is never likely to equal the potential productivity in an environment free from water deficits. Plant improvement aspects are discussed in this paper, with special reference to chickpea and pigeonpea.

The Problem

An adequate knowledge base exists on changes in morphological, anatomical, and basic physiological and biochemical processes in response to drought (Mussell and Staples 1979; Turner and Kramer 1980; Paleg and Aspinall 1981; IRRI 1982). The missing link in this chain, however, is the integration of the physiological and biochemical parameters into simple morphological indices that reflect those changes in response. A particularly weak link, in variable moisture environments, is the development of reliable and reproducible laboratory and field techniques to identify the genotype by environment (G x E) interaction that forms the basis of crop adaptation.

Success in drought research requires the development of breeding and screening methodologies, including criteria for selection. These depend to a large extent upon the nature of the drought environment, which must be accurately defined before genotypes are screened for adaptation to drought. The probability of success for genetic improvement is greater in stored moisture environments than in variable moisture environments (Boyer and McPherson 1975; Quisenberry 1982). This is because the intensity of drought can be predicted fairly accurately before a crop is planted in stored moisture environments but not in variable moisture environments.

Factors in Plant Adaptation to Drought

Plant Stands

In arid and semi-arid environments, soil moisture in the seedbed is often suboptimum, and nongermination of viable seeds leads to poor plant stands with consequent yield reductions. In crops considered to be better adapted to drought, such as sorghum and millets, yield reductions in dry years are largely associated with poor plant stand establishment (Martin and Leonard 1967).

Differences between crop species in ability to germinate at reduced matric potential are known to exist (Hadas and Stibbe 1973; Sharma 1973; Sharkawi and Springual 1977). Very little information is available on variation within a species for seed germination and stand establishment at different matric potentials.

Drought Escape, Avoidance, and Tolerance

Plants adapt to drought environments either through escape, avoidance, or tolerance mechanisms (May and Milthorpe 1962). Major breeding successes have been achieved, however, only in the selection for escape. Isolated cases have been reported of improved adaptation through avoidance characteristics, such as in soybean (Boyer 1982) and wheat (Hurd 1976), and through tolerance characteristics, such as in wheat (Morgan, J.L.; cited in Boyer 1982).

Selection for escape is relatively easy, particularly for crops, such as wheat or chickpea, that are grown in stored moisture environments. Early-maturing types that set seed before water becomes limiting are best adapted to such conditions. In variable moisture environments, selection for escape is more difficult because the least sensitive physiological stages of growth cannot be matched reliably with stress periods, which are highly unpredictable.

Improvement and Stability of Yield in Drought Environments

Working Definition of Drought

Drought has many definitions, depending on the context in which it is used (May and Milthorpe 1962; Blum 1980; Kramer 1980; Simpson 1981; Swindale and Bidinger 1981). In agriculture, production is the primary objective and drought needs to be defined and measured in terms of its effects on biomass and yield reduction or crop losses. Quisenberry (1982) has defined "drought resistance" as the ability of a genotype within a species to be relatively more productive than others under moisture deficits. It is this definition that is followed in this presentation.

Screening Techniques

Creating a representative and repeatable drought stress environment under field conditions is the primary requisite to screen and breed for adaptation to drought. This is relatively easy for stored moisture situations. In variable moisture environments, however, the use of facilities such as rainout shelters in a breeding program has its limitations in terms of space, and, consequently, in its effectiveness.

Breeding Cultivars for Adaptation to Drought

Genotypic variability in drought environments is smaller than environmental variability, and this masks G x E interactions (Frey 1964; Johnson and Frey 1967; Daday et al. 1973; Blum 1982). In order to detect such interactions, precise measurements of the trait are required, with its variability due to other sources either minimized or accounted for. Since promising genotypes selected in favorable environments do not necessarily perform relatively well in drought environments (Hurd 1976; Schonherr 1976), specific selection for drought environments seems necessary. In crops where G x E interactions are strong, as in chickpea, breeding for specific environments becomes inevitable.

A Case Study with Chickpea

Chickpea (*Cicer arietinum* L.) is grown as a winter crop in India, Pakistan, Bangladesh, and Nepal, which account for nearly 90% of the area sown to the crop worldwide (Saxena, N.P. 1984). It is an important spring crop in West Asia and the Mediterranean region. It is generally grown on stored soil moisture and does not receive irrigation. Fields are normally kept fallow in the preceding rainy season, and cultural practices are adopted to conserve moisture in the soil profile. Planting is usually done in late October or early November in the Indian subcontinent, when climatic conditions are favorable (max. temp. <28°C; min. temp. <17°C; open-pan evaporation values 3-5 mm day^{-1}; see Fig. 1). In West Asia, planting traditionally occurs in mid-March.

In the Indian subcontinent, high temperatures and evaporative demand between the end of the monsoon rains and time of sowing result in a rapid loss of soil moisture. Consequently, surface layers of the soil dry up, and moisture in the seeding zone is often insufficient for proper germination, emergence, and good stand establishment.

Once the crop is established, it is exposed, with time, to progressively increasing degrees of soil and atmospheric drought (high temperatures and evaporation). The onset of these stresses is early and more severe in warmer environments, such as at Patancheru in peninsular India (see Fig. 1) and in spring plantings in West Asia. These stresses are relatively milder at Hisar in northern India (see Fig. 1) and in Pakistan, or in winter sowings in West Asia (Saxena, M.C. 1984). In the latter areas, well-distributed winter rainfall and low evaporative demand (open-pan evaporation <2 mm day^{-1} for a period of 2 months) during crop growth partly alleviate the soil moisture deficit and permit better plant growth before the onset of drought.

Although chickpea is deep rooted and explores depths greater than 120 cm, the bulk of the roots (80%) are present in the top 60-75 cm soil layer from where most of the water is used (Sheldrake and Saxena 1979). As a result, the plants experience progressively increasing water deficits from emergence onward. Chickpea responds to irrigation in areas where the winter rainfall is negligible (Saxena and Yadav 1976). The responses are larger in peninsular India where atmospheric drought is more severe than in northern India (Saxena, N.P. 1984). In West Asia chickpea is traditionally planted in spring and is subjected to unfavorable thermal and moisture regimes, which cause a lower yield than in the winter-sown crop (Saxena, M.C. 1984).

The ratio of yield in farmers' fields to the demonstrated yield potential in drylands has decreased considerably over time in India (1:1.1 in 1976/77, 1:2.3 in 1977/78, 1:2.1 in 1978/79, and 1:7.2 in 1979/80; Rastogi 1983). This suggests that a large yield potential is not harvested because of environmental stress factors.

Stand Establishment

Plant stands of chickpea are often poor in the semiarid regions of India. A preliminary survey on plant stands was conducted, in collaboration with ICRISAT economists, in farmers' fields in two districts of Maharashtra state in peninsular India. In one district, plant stands of chickpea were poor because of limiting moisture. In the other, plant stands were reasonably good as rains had occurred soon after seeding. Poor and irregular stands are often a major cause for the large yield gap between farmers' fields and experiment stations.

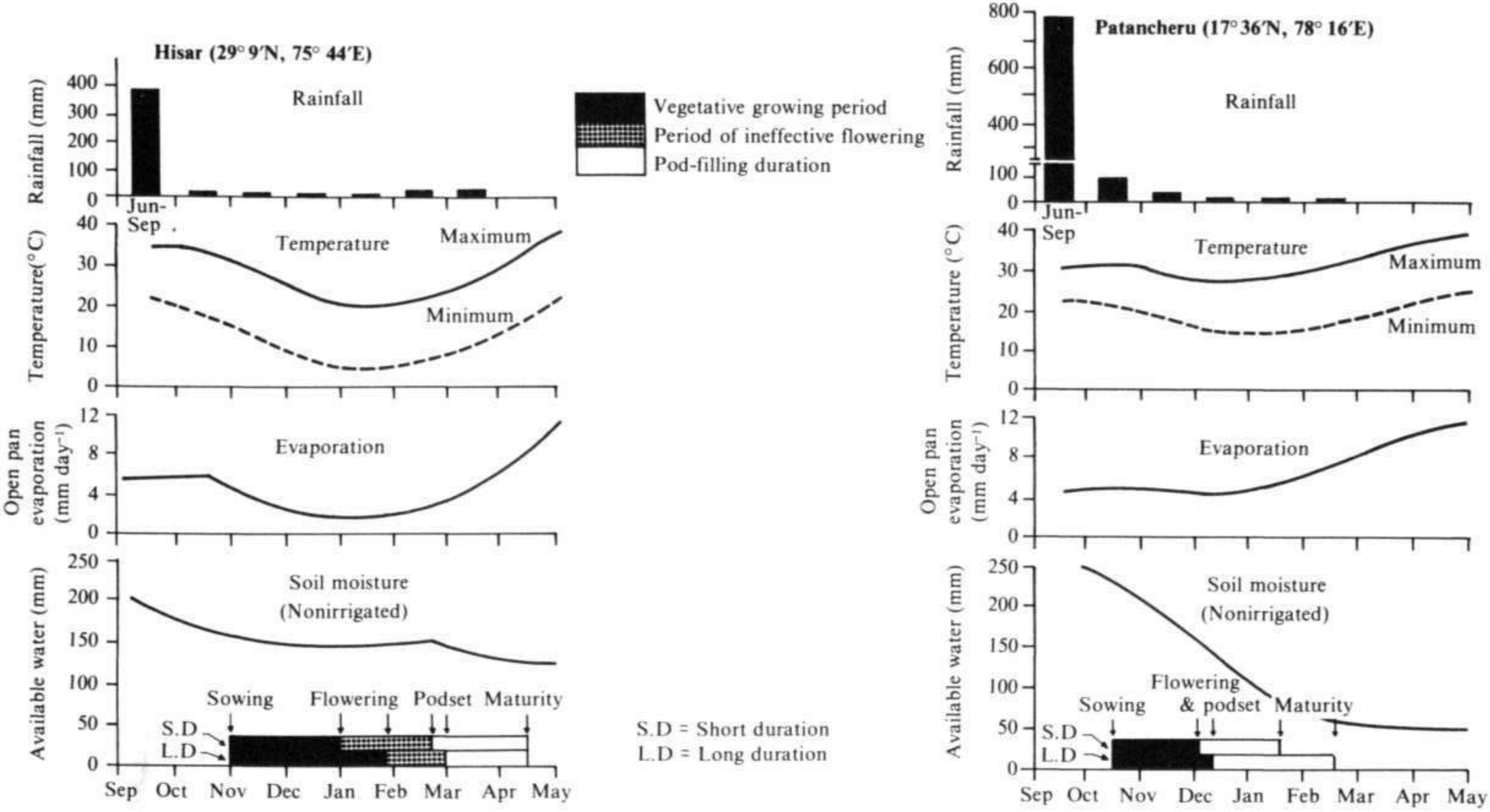


Figure 1. Variation with time in rainfall, atmospheric temperature, open-pan evaporation, and available soil moisture on a Vertisol (depth 150 cm) at Patancheru, near Hyderabad and on an Entisol (depth 100 cm) at Hisar, Haryana during the chickpea-flowering season in India.

Improved plant stands can be achieved by placing the seeds at soil depths where moisture is adequate for germination and emergence, using appropriate implements. Alternatively, genotypes can be selected for their ability to germinate and emerge at suboptimal seedbed moisture. This second possibility has been investigated at ICRISAT Center and is discussed here.

Germination of seed does not take place below a critical soil moisture content. This critical value for chickpea is higher than that for sorghum, maize, or cotton (Hadas and Stibbe 1973). Genotypic variation within chickpea cultivars for this trait has been investigated in experiments at ICRISAT.

Laboratory method. Many attempts to identify genotypic differences in germinability have been made in laboratories, using osmotic solutions. In such attempts with chickpea at ICRISAT, differences in germination between genotypes, as well as within a genotype associated with the seed size, have been detected. The osmotic effects of drought are known to be comparable to true drought effects only under the nonlimiting conditions of water movement or where the soil and seed contact is perfect (Sharma 1973). In field conditions, it is difficult to visualize a perfect soil and seed contact. Therefore, instead of osmotic solutions, soils brought to different moisture tensions and packed in seed germination trays at a bulk density of 1.1 were used at ICRISAT. This more closely represents conditions that exist in seedbeds under field conditions. and appears to be more relevant to detect genotypic variation applicable to field conditions.

Results showed that seedlings failed to emerge in a Vertisol at soil moisture contents below 20%. The field capacity of this Vertisol is around 34% and permanent wilting around 19%. Genotypic differences were noted at 21 % (2.7 bars) and 22% (4 bars) soil moisture content (Fig. 2, Table 1). Susceptible and tolerant genotypes identified in the germplasm by using this screening method (21% moisture content) were tested further by a field method.

Table 1. Mean squares for the effect of moisture percentage in soil in seed germination trays on germination and emergence of chickpea.

Source of variation	Germination (%)	Emergence (%)
Moisture *(%)*	55.40*	15.91
Cultivars	12.48**	19.40**
Interaction	2.07	3.72**

* = significant at the 5% level of probability.
** = significant at the 1% level of probability.

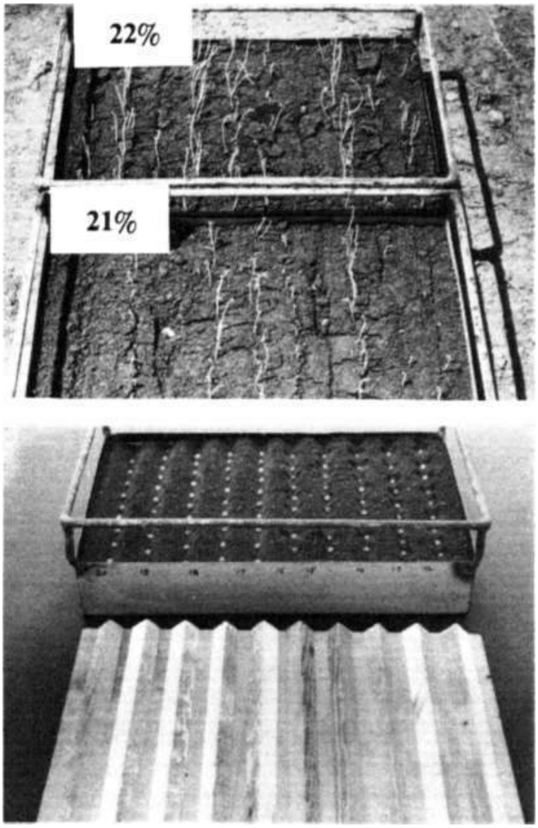


Figure 2. Method of placing seeds in germination trays (bottom) and genotypic differences in emergence at 21% and 22% soil moisture content (top).

Field method. The field testing was conducted on a deep Vertisol (field capacity 32% w/w and 220-250 mm water-holding capacity in a profile depth of 2 m) at ICRISAT Center. The field was uniformly irrigated with an overhead system using perforated pipes. Seeding was then done at a uniform depth of 5 cm on different dates, to obtain contrasting differences in soil moisture contents at the time of seeding.

During the course of the experiment, no rainfall was received. Counted numbers of seeds were sown in each subplot. Soil moisture at 0-10 cm soil depth was determined gravimetrically at three places in each replicate plot. The percentages of seedlings that emerged were computed.

A significant reduction in seedling emergence occurred when soil moisture content was around 20% (Fig. 3). This critical moisture content was similar to the value (21%) obtained in the laboratory experiments.

Genotypic variation. The interaction between cultivars and sowing dates for the percentage of seedlings that emerged was significant and indicated genotypic differences for germination and emergence in limited seedbed moisture (Table 2). This method enables field screening of a large number of genotypes for this trait. Times of sowing need to be selected depending on soil type and weather conditions (temperature and evaporation) in the test region.

Correlation between the laboratory and field results. The correlation between laboratory results and field performance was 0.78 ($P < 0.10$, $n = 6$). Further experiments to evaluate the two techniques are in progress at ICRISAT. Use of the two techniques together should enable effective selection of genotypes best suited to overcome the problem of uneven plant stands of chickpea in nonirrigated conditions.

Drought Tolerance

Chickpea is believed to be more tolerant of drought conditions, but there is hardly any published evidence to support this contention (Saxena, N.P. 1984). Research on plant responses to drought in this crop has been limited (Sheldrake and Saxena 1979; Singh and Bhushan 1979; Keatinge and Cooper 1984). There are no reports on screening genotypes for adaptation to drought. Attempts in this direction at ICRISAT are reported here.

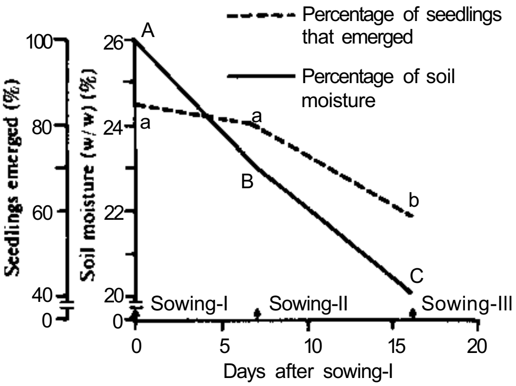


Figure 3. Decrease with time in soil moisture content (w/w) in the top 0-10 cm soil depth, and in percentage of seedlings that emerged.

Table 2. Seedlings that emerged in sowing III expressed as percentage of numbers that emerged in sowing I and their arcsin transformation.

Cultivar	Seedling emerged (%) (Sow-III/Sow-I)	Arcsin transformation
K 850	66.4	56.0
G 130	81.8	64.8
Annigeri	88.4	70.5
Rabat	90.0	79.4
K 4-1	54.2	47.2
L 550	38.5	37.7
SE±	-	8.02
CV (%)	-	23.4

In peninsular India, the soil drought situation in the postrainy season is better defined because of relatively less interference from winter rainfall (see Fig. 1). The progressive development of soil drought depends upon the amount of moisture stored in the soil and the rate at which it is lost through evapotranspiration. Plants suffer from water deficits early in the season, and the fall in shoot water potential from sunrise (-2 bars) to midday (-12 bars) is quite sharp even before the crop flowers. The magnitude of water deficit progressively increases with advancing growth. The nature of drought leads to adaptation of genotypes of shorter growth duration (85-90 days, see Fig.4).

Methodology. On deep Vertisols, it is not possible to effectively impose and regulate the onset of receding soil moisture treatments. On the other hand, these treatments can be created with ease on relatively deep Alfisols. The Alfisol used for experiments reported here was around 1.3 m deep with a profile water-holding capacity of about 150 mm. In nonstress treatments, irrigation at 10-day intervals was required to maintain the plots around field capacity. Receding soil moisture treatments were created by withholding irrigation soon after 50% flowering. The severity of stress can be altered in this method by withholding water either early or late in the season. This method permitted application of reproducible stress treatments from year to year.

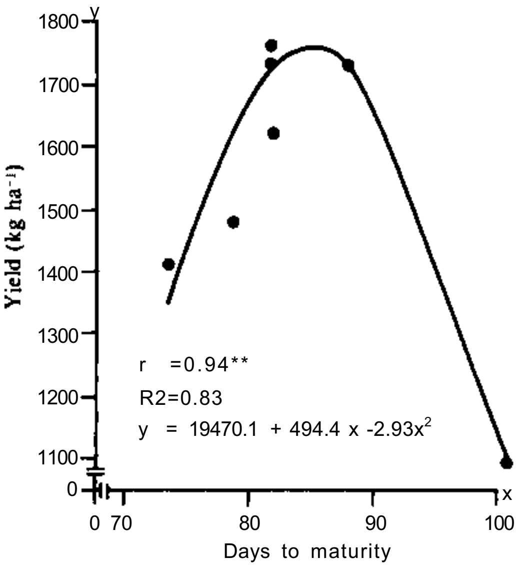


Figure 4. Relationship between growth duration (days to maturity) and yield (mean of three plant densities) in eight cultivars of chickpea grown on a nonirrigated Vertisol.

In order to screen large numbers of germplasm lines, a nonreplicated augmented design was used with appropriate check cultivars adapted to the region. These genotypes were grown in both a nonstress and a drought environment. The genotypes identified as tolerant and susceptible in these screenings were tested further in replicated tests in a split-plot design, with irrigations constituting the main plots and genotypes the subplots.

Genotypic variation. In a group of genotypes that had a wide range in days to flowering (30-77 days), a significant negative correlation between days to flowering and stress yield was observed in the Patancheru environment (Table 3). On the other hand, yield potential (irrigated yield) was positively correlated with stress (nonirrigated) yields.

A drought index, independent of the effect of potential yield, was computed for wheat by Fischer and Maurer(1978). Bidinger et al. (1982) computed a drought index for terminal water stress in pearl millet, independent of the escape and potential yield, using a multiple regression approach:

$$\hat{Y}o = a - b\ F + cY_1$$

and

$$\text{Drought index (standard residual)} = \frac{Yo - \hat{Y}o}{\text{Standard error of } Yo}$$

where

Y_0 = stress yield,

Y_0 = regression estimate of stress yield,

Y_1 = nonstress yield, and

F - days to flowering.

The same method was followed in chickpea to compute drought indices.

In this approach, a common multiple regression for the entire set of genotypes is established to predict the stress yields, taking into consideration the yield potential (Y_1) and days to flowering (F). The variation (residuals) in stress yields (Yo) not accounted by yield potential (Y_1) and F(escape) was used to develop an index of drought tolerance. The susceptibility or tolerance of a genotype was indicated by the sign of the drought index. If negative, it indicated that the performance of the genotype was poorer than expected; if positive, it indicated that the genotype performed better than expected. For the purpose of identifying tolerant and susceptible genotypes, a standard residual of 1.3 or greater was considered. This represented the genotypes in the

Table 3. Simple correlation coefficients, days to flowering vs. stress yield, and stress yield vs. nonstress yield, on an Alfisol.

Group	Days to flowering	Observations (no.)	Days to flowering vs. stress yield	Stress vs. nonstress yield
All	30-77	483	-0.59**	0.49**
Group I	30-40	117	0.04	0.30**
Group II	41-50	258	-0.30**	0.44**
Group III	51-60	73	-0.13	0.46**
Group IV	61-77	35	-0.18	0.19

** = significant at the 1% level of probability.

upper and lower 10% of the normal distribution of these indices. At a probability of 80%, the observed differences thus represented true effects rather than just random effects.

Such an analysis indicated that escape and yield potential accounted for 45% of variation in yield in that environment; the remainder was due to inherent drought susceptibility or tolerance of the genotypes (Table 4).

Late chickpea genotypes suffered more seriously from the kind of stress described earlier (see Table 3), and they were generally more susceptible than the early types. Therefore, in evaluating drought tolerance, the genotypes were separated into narrow groups on the basis of days taken to flowering (Table 4). This minimized the effects of escape within each group, except in group II.

The first two groups of genotypes are of great interest in peninsular India, where factors other than earliness and yield potential are responsible to a great extent (80-90%) for the adaptation of genotypes in stress environments. It was possible to identify genotypes within a duration group quite similar in potential yields but with contrasting differences in drought tolerance and yield in drought environment (Table 5). Results in pearl millet also indicated that the technique was useful in identifying genotypes better adapted to intermittent stresses, particularly the midseason stress (Bidinger et al. 1982).

Correlation of results in Alfisols and Vertisols. Chickpeas are usually cultivated on Vertisols and drought tolerance of genotypes in the present study was evaluated on an Alfisol. To evaluate the validity of that technique, performance of a few genotypes was compared in a given year on these two soil types. The correlations were positive and high (r = +0.85**, n-2 = 47). This indicated that screening for drought tolerance on Alfisols, where reproducible drought conditions can be created from year to year, could reliably predict responses of genotypes on heavier soil types.

Table 5. Some characteristics of two germplasm lines tolerant and susceptible to water deficits on an Alfisol.

	Genotypes	
Characters	ICC 10448	ICC 10985
Alfisol		
Days to flowering	53	49
Days to maturity	82	78
Drought index	+ 1.5	-1.3
Nonirrigated yield (kg ha^{-1})	800	471
Irrigated yield (kg ha^{-1})	1162	1074
Vertisol		
Nonirrigated yield (kg ha^{-1})	2054	1227

Overcoming escape effects. The duration of a genotype interferes with the comparison of drought tolerance in very diverse groups of genotypes because of the differences introduced by the escape effects. This was minimized in chickpea by taking advantage of its being a quantitative long-day plant. The long-day treatments (24 hours photoperiod) were imposed soon after seeding. This resulted in nearly synchronous flowering (within 2 days of each other) in a group of genotypes that differed by 30 days in flowering time under natural day conditions. Drought treatments were then imposed as described earlier.

In the small set of genotypes used in this experiment, which had a wide range of flowering times, no contrasting differences in drought tolerance were

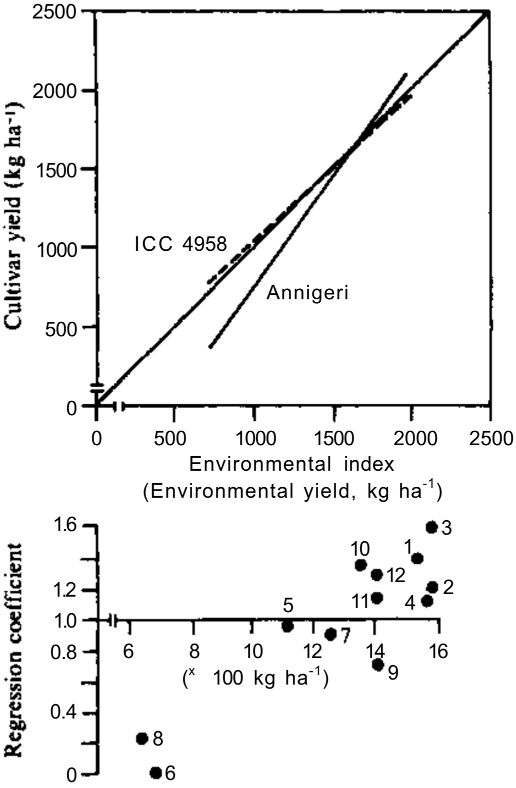
Table 4. Correlation coefficients (R^2) and test of significance of the regression coefficients and mean seed yield in chickpea.

			Calculated t values of regression coefficient		Mean seed yield (kg ha^{-1})		
Maturity group	Days to flowering	R^2	Days to flowering	Irrigated yield	Nonirrigated Vertisol	Irrigated Alfisol	Nonirrigated Alfisol
All	30-77	0.45	-13.25**	9.04**	1120	1506	472
Group I	30-40	0.092	0.025	3.38**	1298	1701	598
Group II	41-50	0.22	-3.32**	6.70**	1180	1524	494
Group III	51-60	0.21	-0.12	4.11**	857	1239	302
Group IV	61-77	0.056	-0.86	0.92	631	1286	239

** = significant at the 1% level of probability.

detected. The experiment needs to be repeated with a larger number of genotypes.

Verification of results. On a set of genotypes, the commonly used stability analysis (Eberhart and Russell 1966) was performed. It can be used to define drought resistance in terms of yield when the major environmental factor affecting yield is drought stress. The analysis revealed that the genotypes rated as tolerant on the drought index criteria also produced more stable yields in drought environments than did other irrigation-responsive genotypes (Fig. 5). A proposed scheme for genetic improvement of drought tolerance in chickpea is outlined in Figures 6 and 7.



1. Annigeri
2. K-850
3. JG-74
4. P-1329
5. ICC 7684
6. ICC 10985
7. ICCL 82001
8. ICC 10991
9. ICC 4958
10. ICC 10428
11. ICC 11051
12. ICC 10448

Figure 5. Stability of chickpea yield in stress environments. Diagonal line (top) indicates 1:1 slope.

Future Research Needs

1. There is a need to define and classify the various drought environments. Iso-drought environments need to be identified.
2. Field screening capabilities as described in this paper should be developed at least at one location for each iso-drought environment.
3. Segregating populations involving common crosses should be advanced in the drought and nonstress environments. This should facilitate decisions on whether selection for specific adaptation to drought environments is necessary.
4. The strong G x E interaction in chickpea is a limitation on screening large numbers of germplasm lines in a season. In view of the limitations generally associated with pot culture techniques in drought work, attempts should be made to develop a pot technique so that a large number of genotypes can be narrowed to a few promising ones for further testing in field experiments.

Present Status of Pigeonpea Research

Pigeonpea (*Cajanus cajan,* (L.) Millsp) is generally considered to be a crop adapted to drought conditions and ideally suited to semi-arid areas (Sheldrake 1984). The observations that among the rainy-season crops pigeonpea appears to utilize maximum soil moisture under rainfed conditions (Bains and Choudhary 1970) and that it can produce some yield in situations where other crops fail (Pathak 1970) lead to such a conclusion. Studies on the drought tolerance characteristics of this crop, however, have been limited.

Environment

The soil and climatic environments in which pigeonpea is grown have been comprehensively identified by Reddy and Virmani (1981). The probabilities of assured rainfall at the time of sowing of this crop are low, and the chances that the seedling will survive are only about 50%, depending upon adequacy of soil moisture in surface layers (Binswanger et al. 1980).

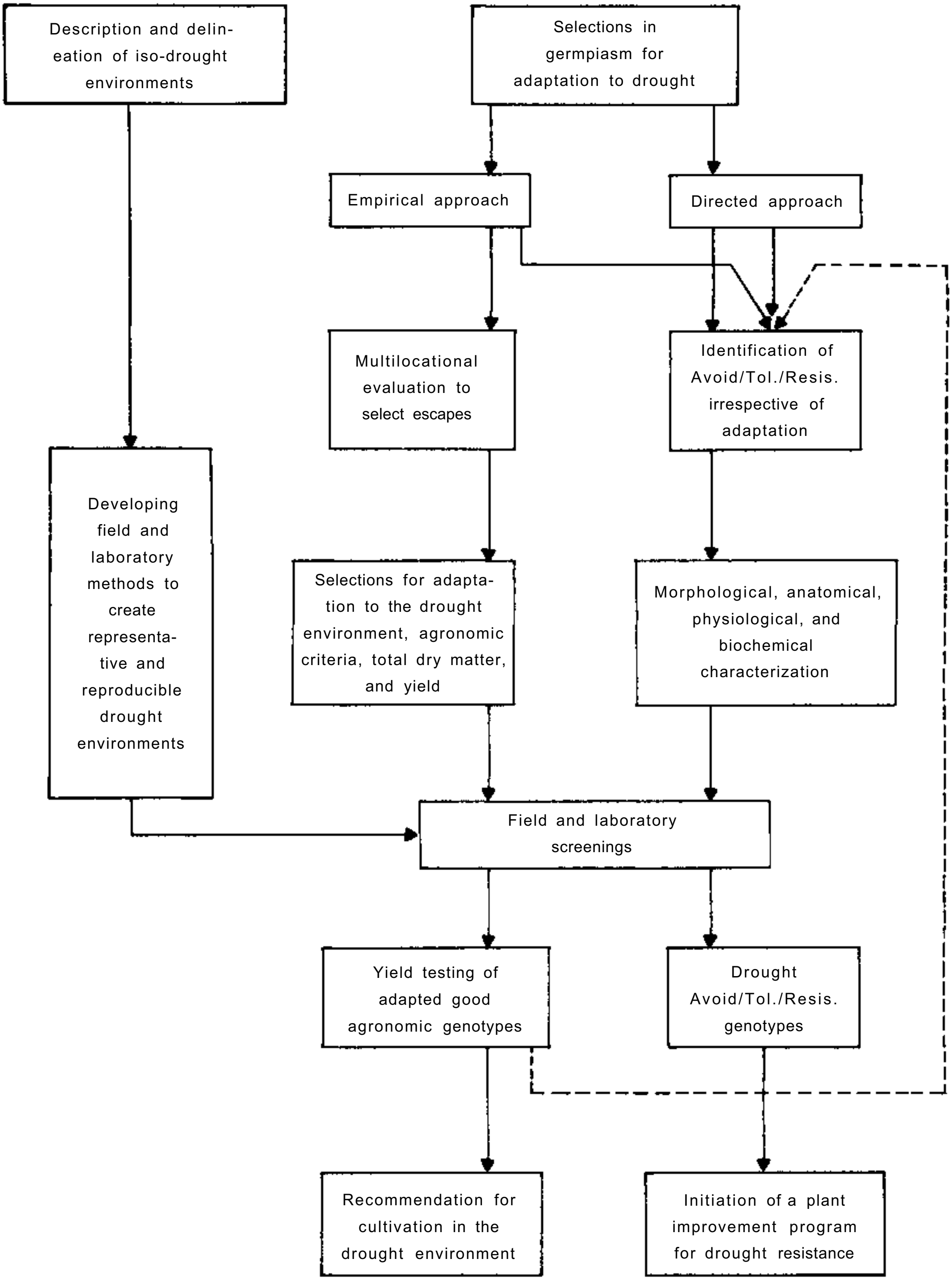


Figure 6. Suggested procedure for identifying drought-tolerant chickpea genotypes.

In India, although most areas sown to pigeonpea appear to have dependable rainfall, the crop is subjected to varying degrees of drought depending upon growth duration of the genotype and upon soil type. In spite of its deep root system, pigeonpea meets half of its water demand from the upper 50 cm of the soil layer (Sardar Singh and Russell 1981), which is depleted rapidly with crop growth. Fluctuations in moisture in the top 50 cm of soil will, therefore, lead to periodic water deficit.

Medium- and long-duration pigeonpeas planted in the rainy season experience, as do sorghum and pear millet, intermittent water deficit during vegetative stages of growth. In the postrainy season, such pigeonpeas are exposed to progressively increasing soil and atmospheric drought during flowering and podfill stages, similar to chickpea. Short-duration pigeonpea, however, is exposed only to intermittent soil moisture deficits during the rainy season. The severity of soil drought in pigeonpea is modified by the cropping system and the cropping pattern.

Responses to Drought

There is excellent documentation of soil moisture use and evapotranspirative losses in medium-duration pigeonpeas, which grow in the rainy and postrainy season on deep Vertisols in peninsular India (Sardar Singh and Russell 1981).

The effect of water stored in the soil on the yield of medium-duration pigeonpea during the postrainy season was assessed by alleviating drought stress through irrigation at ICRISAT Center. Water deficit drastically reduced yields, and the extent of yield reduction depended on soil type: 100% in an Alfisol and 20% in a Vertisol (Y.S. Chauhan, personal communication). Responses to irrigation in the postrainy season pigeonpea are large (Rao et al. 1983), indicating severe water deficits in that cropping system. These findings and observations cast doubt on the common belief that pigeonpea is a particularly drought-resistant crop.

Cultivaral differences in response to irrigation were reported in the West Indies (Keatinge et al. 1980). The moisture deficit in these studies seems to have been confounded with plant density effects.

Analyzing the yield data from multilocational trials, Sinha (1981) concluded that variation in pigeonpea yields is not related to variation in total precipitation but perhaps to its distribution. He reported large responses to irrigation in his experiments.

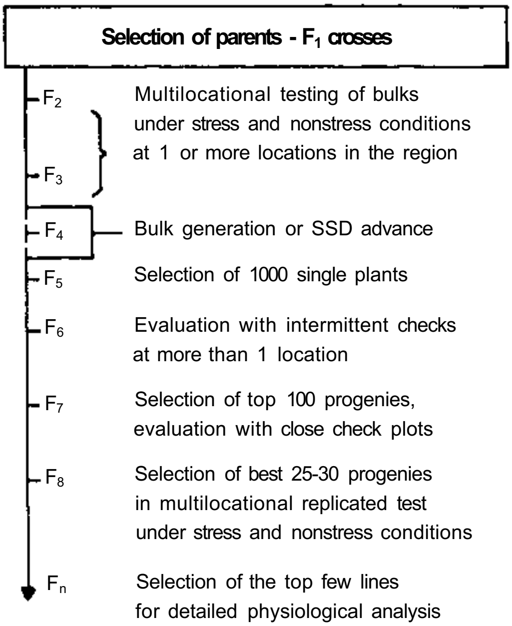


Figure 7. Outline of steps for a breeding program (Sharma and Saxena 1979).

Quantification of the effects of drought is very difficult in pigeonpea. For example, the long growing season for medium- and long-duration pigeonpeas permits recovery from intermittent drought effects. But such a recovery is not possible in short-duration pigeonpea. The periods of occurrence of these stresses are unpredictable, and they cannot be easily regulated in field experiments.

Screening for Adaptation to Drought

There are no reports yet on screening a large number of pigeonpea genotypes for adaptation to drought, but something certainly can be done to screen genotypes for adaptation to terminal drought. The methodology reported earlier in this paper for screening chickpea genotypes can be used to handle the terminal stress in medium- and late-duration pigeonpea and for postrainy-season pigeonpea.

Future Research Needs

To date very little attention has been paid to water relations in pigeonpea. Evidence gathered so far has created more uncertainty. Research activities that need immediate attention are:

1. Investigations of genotypic differences in seedling mortality in response to inadequate soil moisture.
2. Studies to determine the extent to which rainy-season pigeonpea of different durations suffers from drought on different soil types.
3. Quantification of the effect of intermittent drought in the vegetative stages of growth and of terminal drought in the reproductive stages of growth on final yield in medium- and late-duration rainy-season pigeonpea. The following questions need to be explored:
   a. Do short-duration genotypes escape terminal water stress and therefore produce higher yields than do medium-duration genotypes in peninsular India?
   b. Are short-duration genotypes affected by intermittent drought to a greater extent than medium- and long-duration genotypes because they have little time to recover from the stress?
4. Using methodologies developed for chickpea, screening pigeonpea genotypes of similar growth durations for genotypic differences in tolerance to terminal soil drought. Work on mechanisms of drought tolerance can then follow if genotypic differences are found.
5. Using the methods developed for chickpea, screening postrainy-season pigeonpea for adaptation to drought.
6. Development of a methodology to screen for genotypic differences in tolerance to intermittent drought during the rainy season.

Conclusions

Further work on responses to drought in field experiments is required in both chickpea and pigeonpea. Prospects appear promising to improve the adaptation of these crops, both to stored soil moisture and to progressively increasing soil and atmospheric drought. Screenings on adaptation need to be extended to more locations, covering at least one site for each iso-drought environment. Serious attempts also need to be made to screen for intermittent drought in pigeonpea.

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The Effects of Waterlogging on Root Growth and on Symbiotic Nitrogen Fixation by Legumes

K.A. Smith[1]

Abstract

This paper reviews the chemical processes that occur in waterlogged soil, the effects of waterlogging on root growth of legumes and other agricultural crops, and its effects on the symbiotic fixation of nitrogen. The paper then discusses the mechanisms thought to he responsible for sensitivity to, or tolerance of, anaerobic conditions in the soil. Crop species vary widely in their response to flooded conditions, and legumes, with a few exceptions, are generally regarded as among the most sensitive species. Tolerance of waterlogging appears to be associated with the capacity to develop oxygen-conducting aerenchyma within roots, and with a rate of endogenous ethylene production too low to inhibit root extension. Similarly, the capacity of leguminous nodules to survive and fix nitrogen in waterlogged soil is associated with the ability to develop a loose structure that facilitates gaseous exchange. Nitrogenase activity is especially sensitive to ethylene, and the rate of endogenous ethylene production under oxygen-deficient conditions may be an important factor in determining the sensitivity of legumes to waterlogging. More research in this area is needed, but sufficient evidence exists to consider testing for low ethylene production as a useful means of screening varieties for likely tolerance to waterlogging.

Introduction

The flooding of soils has had a major impact on agriculture throughout history, the effects being beneficial in some circumstances, adverse in others. From the earliest times, the alluvial soils of the floodplains and deltas of the major rivers of the world have been the sites of human settlement. Silt carried down from the upper reaches of rivers has been regularly deposited on these areas as a result of natural flooding or of basin irrigation (which has been practiced for nearly 7000 years [Marr 1967]); this process has played an important role in the maintenance of soil fertility.

The adverse consequences of flooding are, of course, due to the damage it causes to all but a few crops. Although there appear to be no detailed statistics available of the area of agricultural land which is annually subject to waterlogging, or of the value of crop losses, it is generally accepted that these are very significant, in irrigated as well as in rainfed agricultural systems. According to FAO and UNESCO (1973), the total irrigated area in the world was expected to reach 200 million ha by 1975 and possibly 300 million ha by the end of the century, and "drainage and salinity problems will increase more than proportionately." A few years ago, it was estimated that about 80 million ha of land was drained, mostly in the subtropical and temperate zones; the recognition of drainage as an essential complement to irrigation for permanent irrigated agriculture is now leading to the development of drainage facilities faster than ever before (FAO and UNESCO 1973). A good illustration of the problem is the situation in western Canada, where more than 280 000 ha of land are irrigated and about 24000 ha are permanently waterlogged and, therefore, not cropped at all because of water seepage from irrigation channels (Kozlowski 1984).

Not much systematic research has been done on

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the relative tolerance of crop plants to waterlogging, but it is recognized that leguminous crops such as peas and beans are particularly sensitive (FAO and UNESCO 1973). To take one example from a tropical environment, waterlogging is regarded as a major problem in the growth of the important pigeonpea crop on deep Vertisols in India (Reddy and Virmani 1981). This paper attempts to review the processes involved in waterlogged soil and in root metabolism—which result in adverse effects on plant growth—with particular reference to legumes and the symbiotic fixation of nitrogen, and to identify the principal factors determining tolerance to waterlogging.

Chemical Changes in Waterlogged Soils

The concentration of oxygen present in a soil reflects the balance between supply—primarily by diffusion from the atmosphere—and the respiratory demand of both plant roots and microorganisms. In a well-drained soil with a satisfactory structure, the air-filled pore space at field capacity will be of the order of 0.2-0.3 $m^3\ m^{-3}$, and the concentration of oxygen is unlikely to fall much below the atmospheric level of 0.21 $m^3\ m^{-3}$. Conversely, the product of respiration, CO_2, can easily diffuse out of the soil.

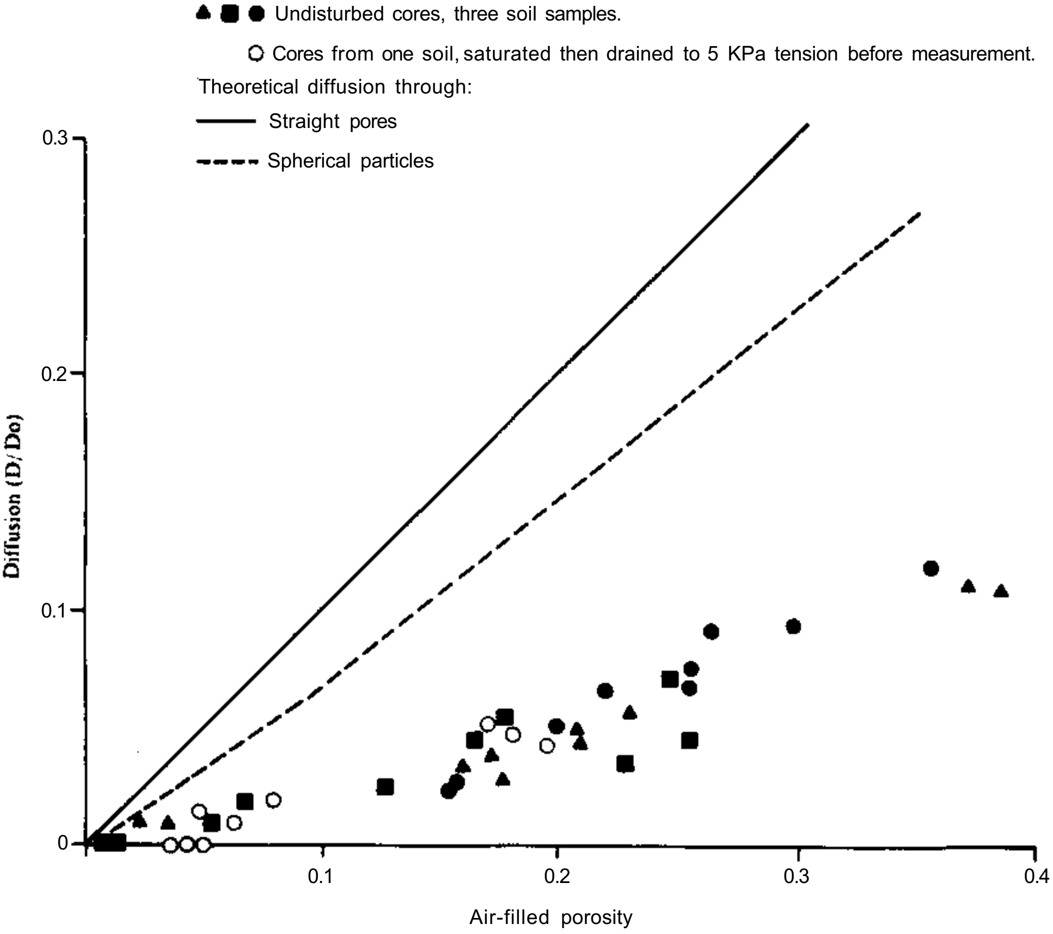

Figure 1. Effect of air-filled porosity on diffusion of gases in undisturbed samples of silt loam top soils under pasture. (After Gradwell 1961.)

The rate at which soil oxygen is respired is mainly controlled by temperature and the availability of substrates for microbial respiration (Bunnell et al. 1977; Jenkinson 1977). Montieth et al. (1964) showed that, over the narrow range of temperatures found in temperate regions, the respiration rate for bare soil at temperature To, RT, was given by RT = Ro $Q^{T/10}$, where Ro is the respiration rate at 0°C and Q is a factor for the increase in rate for a 10°C rise in temperature (commonly known as the"Q_{10}").

They obtained Ro values of 1.2 g m^{-2} day^{-1} for the period February-August and 0.9 $m^{-2}day^{-1}$ for September-January, with a Q_{10} value of 3. They attributed the difference in Ro to a decline in organic matter and hence respiratory substrate after a spring flush of microbial activity. Other reported values for Q_{10} have generally been between 2 and 3.

When soil becomes waterlogged, the quantity of oxygen immediately available to support aerobic respiration is greatly reduced because of the low solubility of the gas in water. Also, the rate of replenishment of respired oxygen is even more drastically reduced because the rate of diffusion in solution is only of the order of 10^{-4} times the rate in the gaseous phase. At water contents halfway between field capacity and saturation, the diffusion rate of gases through the soil falls steadily with the decline in air-filled pore space (Fig. 1). Under conditions in which the demand for oxygen exceeds supply, whether or not the soil is completely waterlogged, the oxygen concentration falls. If it reaches a level equivalent to about 3×10^{-9} mol O_2 m^{-3} in solution, aerobic respiration ceases (Greenwood 1961), and from then on respiration is confined to facultative, and subsequently obligate, anaerobic microorganisms.

Anaerobic organisms have the capacity to substitute another terminal electron acceptor for molecular oxygen. These acceptors may be either oxidized inorganic substances or dissimilation products of soil organic matter, and are reduced in sequence, depending on their thermodynamic redox potential (Table 1). This subject has been comprehensively reviewed by Ponnamperuma (1972, 1984). As can be seen from Table 1, when all available oxygen has been consumed, nitrate is the most easily reduced substance. It is converted first to nitrite, subsequently to dinitrogen oxide, N_2O, and then to molecular nitrogen, N_2; this well-known process of denitrification depletes the soil's supply of available nitrogen. The redox potential remains -poised- at a fairly constant level while nitrate is being reduced, and then falls again as the next reduction, that of manganese dioxide, becomes the dominant process (Fig. 2).

Table 1. Major duction systems and corresponding redox potentials in flooded soil (After Ponnamperuma 1984).

Reaction	Redox potential at pH 7 (V)
$O_2 + 4H^+ + 4e^- = 2H_2O$	0.814
$2NO_3^- + 12H^+ + 10e^- = N_2 + 6H_2O$	0.741
$MnO_2 + 4H^+ + 2e^- = Mn^{2+} + 2H_2O$	0.401
$CH_3COCOOH + 2H^+ + 2e^- = CH_3CHOHCOOH$	-0.158
$FE(OH)_3 + 3H^+ + e^- = Fe^{2+} + 3H_2O$	-0.185
$SO_4^{2-} + 10H^+ + 8e^- = H_2S + 4H_2O$	-0.214
$CO_2 + 8H^+ + 8e^- = CH_4 + 2H_2O$	-0.244

Although both manganese and iron are necessary in small amounts as essential plant micronutrients, both are toxic in high concentrations. Free soluble sulfides, resulting from the reduction of sulfate, are also highly toxic to plants, but in many soils precipitation as iron(II) sulphide by the Fe^{2+} ions already present prevents the buildup of toxic concentrations (Connell and Patrick 1968).

The main effect on phosphorus after waterlogging is the increase in availability of the orthophosphate ion in both acidic and alkaline soils. In acidic soils this is caused by three processes: release of sorbed P from Fe(III) hydroxides when the iron is reduced to Fe(II); the hydrolysis of iron and aluminum phosphates; and release from anion exchange sites. The first process is a direct result of reducing conditions, while the others are due to a change in pH toward neutrality, which occurs in both acid and alkaline soils after submergence for several weeks (Ponnamperuma 1972). In alkaline soils, this change in pH increases P availability by making hydroxy la patite more soluble (Stumm and Morgan 1970).

Under anaerobic conditions, instead of CO_2 being the sole end product of carbohydrate metabolism, products such as ethanol and low molecular weight organic acids (e.g., acetic and butyric acids) are formed, all of which can cause injury to plant roots (Russell 1977). The most physiologically active organic substance in flooded soil is probably ethylene, which is evolved both by soil microorganisms and by plant roots. The effects of this gas on plant growth and development are discussed in a later section.

Sites of anaerobic activity can occur in soils that are not completely waterlogged as a consequence of heterogeneous soil structure and the distribution of

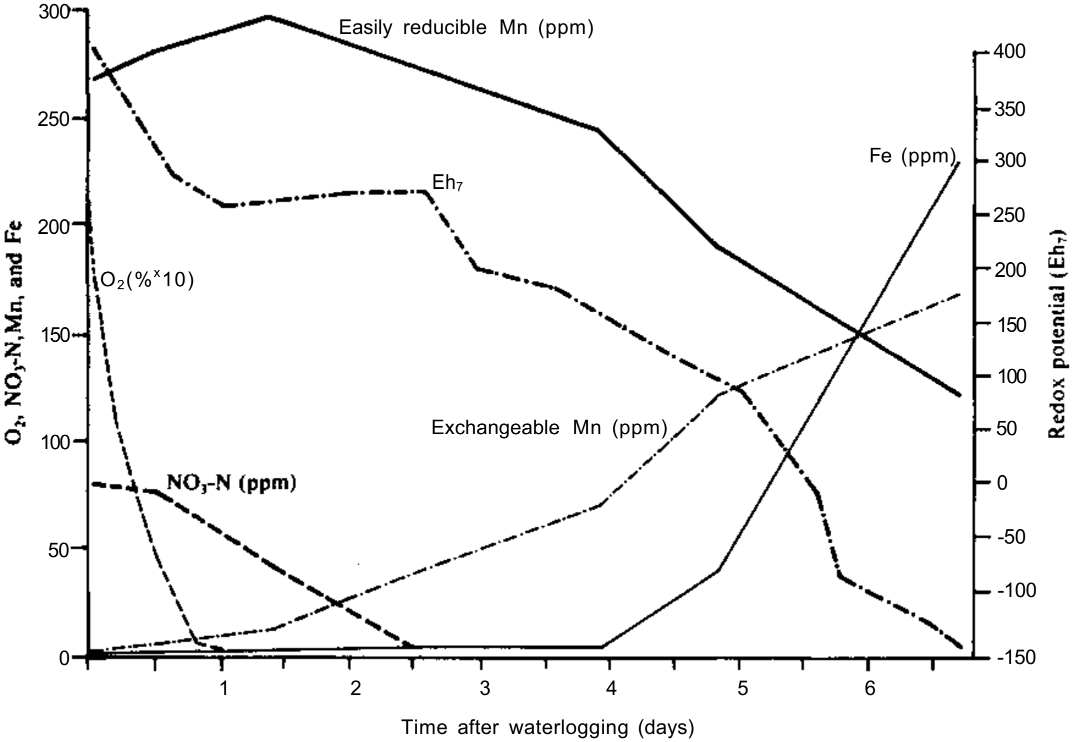

Figure 2. Changes in oxygen, nitrate, manganese, iron, and redox potential in a silty clay as a result of waterlogging. (After Turner and Patrick 1968.)

substances for microbial respiration. For example, in aggregated soils of fine texture the interaggregate cracks and pores may be drained when the aggregates themselves are virtually saturated. Thus, whereas oxygen may readily diffuse throughout the macropore system of the soil profile, diffusion into the aggregates themselves may be sufficiently slow to allow the centers to become anaerobic (Smith 1977, 1980). This is illustrated in Figure 3. A localized accumulation of readily decomposable organic matter in an unstructured soil may also result in oxygen consumption outstripping supply, again bringing about the formation of an anaerobic zone within the soil. The presence of these anaerobic zones or microsites can result in significant losses of nitrogen by denitrification and in the formation of ethylene, which is capable of diffusing away from the site of formation toward plant roots that are still respiring aerobically and extending through oxygenated parts of the nearby soil.

Effects of Waterlogging on Root Growth and Development

The depletion of oxygen in the soil progressively reduces the growth of plant roots by inhibiting aerobic respiration (Lemon and Wiegand 1962; Jackson et al. 1984). The close relationship between root extension growth and both oxygen uptake and oxygen concentration is illustrated in Figure 4. Root growth slows down when the oxygen diffusion rate in the soil falls below that required to sustain normal rates of oxygen consumption by the roots (Blackwell and Wells 1983). Slower oxygen absorption will depress the amount of chemical energy (mostly ATP) produced by the oxidative phosphorylation of adenine nucleotides that is available for growth (Jackson 1983). When the external supply of oxygen ceases altogether, root tips will die, unless there is a pathway for oxygen diffusion within the root. Such

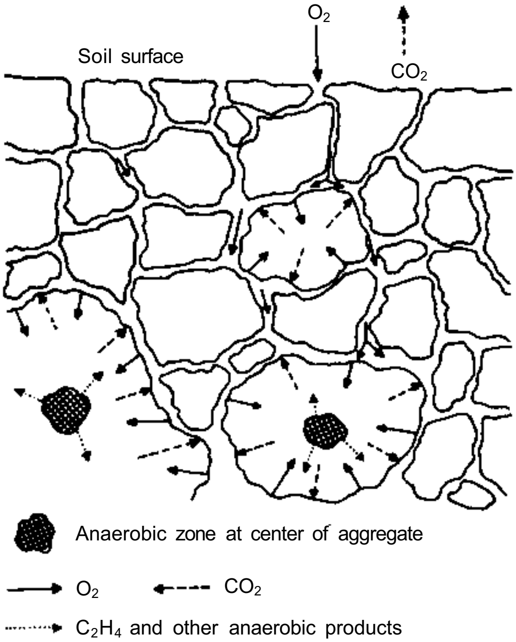

Figure 3. Gas diffusion pathways in aggregated fine-textured soil, and the development of anaerobic zones within the larger aggregates.

pathways, consisting of intercellular air spaces (aerenchyma), are so well developed in rice (*Oryza sativa* L.) that not only is all the oxygen demand of the root tip met, but in addition there is a net efflux of oxygen into the soil (Luxmoore et al. 1970a). Maize (*Zea mays* L.) roots have been shown to transport up to 40% of their oxygen demand in this way (Luxmoore et al. 1970b). There is now evidence that the lysis of cells, which gives rise to the formation of aerenchyma, is promoted, in maize at least, by ethylene (Drew et al. 1981). Although ethylene accumulates in soil under waterlogged conditions, it is more likely that ethylene formed endogenously within the root is primarily responsible for stimulating the formation of aerenchyma (Jackson and Drew 1984). Ethylene biosynthesis in the root is stimulated by small concentrations of oxygen (Jackson 1982; Jackson et al. 1984), and the gas accumulates because of entrapment by an unstirred layer of water. Increased evolution of ethylene also occurs in waterlogged legume roots. A rate of evolution in pea (*Pisum sativum* L.) roots was measured at 3.4 times that of the aerated controls (Huber et al. 1979), and comparable results for broad bean (*Vicia faba* L.) were also reported (Hall et al. 1977).

Early responses of roots to flooding, prior to the complete disappearance of oxygen, are also partly

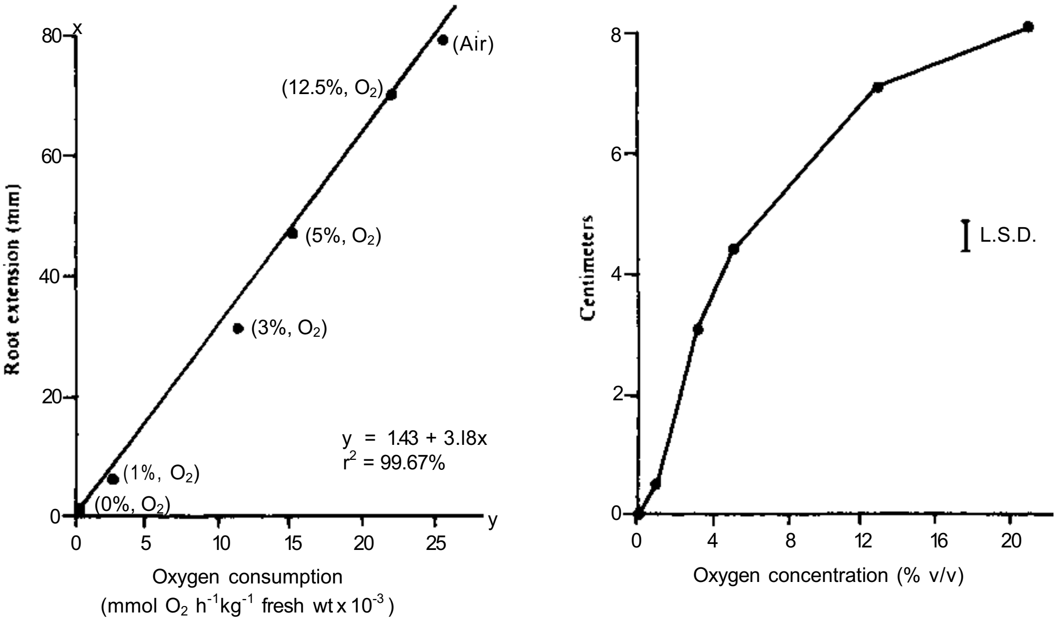

Figure 4. Relationship between root extension of 4-day-old barley seedlings and oxygen consumption and oxygen concentration around the roots (After Jackson et al. 1984).

due to increases in ethylene content (Jackson and Drew 1984). Rice roots are stimulated by low concentrations of ethylene, which are inhibitory to other crops (Smith and Robertson 1971; Konings and Jackson 1979). The slow production rate of endogenous ethylene in this crop results in modest accumulations in flooded roots which are therefore likely to stimulate extension; in contrast, white mustard *(Sinapis alba* L.), with a faster rate of ethylene synthesis, accumulates inhibitory concentrations when the roots are submerged (Konings and Jackson 1979).

Roots of some crops such as tomato (*Lycopersicon esculentum* Mill.) and sunflower (*Helianthus annuus* L.) change their direction of growth to horizontal or even upward instead of downward under flooded conditions. This is probably a reaction to reduced oxygen supply (hypoxia) or an accumulation of trapped gas, and the mechanisms are worth investigating because they enable roots to escape oxygen stress by growing closer to the better aerated soil surface (Jackson and Drew 1984). This change in growth orientation also applies to the adventitious roots that develop from the submerged part of the stem when plants are flooded. The development of an adventitious root system demonstrates the capacity of many species to adapt to anaerobic environments; often the adventitious roots have well-developed aerenchyma, e.g., maize (Drew et al. 1979), wheat (*Triticum aestivum* L.) (Trought and Drew 1980), and sunflower (Kawase and Whitmoyer 1980).

Sensitivity of Legumes to Waterlogging

Relatively few research studies dealing with the effects of waterlogging on plant growth, and of the mechanisms involved, have used legumes as experimental material. Enough information has been amassed, however, from agronomic and physiological investigations to indicate that, with a few exceptions, legumes are generally very susceptible to damage by flooded conditions.

Waterlogging was a major problem limiting the growth of pigeonpea (*Cajanus cajan* (L.) Millsp.) in deep Vertisols in India (Reddy and Virmani 1981). Planting this crop on ridges increased yield by 30% over planting in a flat soil surface, because of the reduction in waterlogging damage (Chowdhury and Bhatia 1971). Work in England under simulated tropical conditions showed that the growth of cowpea *(Vigna unguiculata* (L.) Walp.) is adversely affected by short-term flooding, leading to major reductions in root and shoot dry weight and seed yield, but the plants are capable of surviving long periods of waterlogging and continue vegetative growth as the root nodules adapt and allow nitrogen fixation to continue (Minchin and Summerfleld 1976). Field experiments in Nigeria showed cowpea to be much less tolerant of waterlogging, apparently because of attack by plant pathogens, whereas soybean *(Glycine max* (L.) Merr.) was little affected by the waterlogging treatment (Wien et al. 1979). Experiments with beans *(Phaseolus vulgaris* L.) in Central America showed that significant yield reductions could be brought about by short-term flooding; by growing the plants in cambered beds to promote rapid surface runoff, considerable yield increases were achieved over control plants grown in flat ground (Forsythe et al. 1979). No detailed study of the effect of waterlogging on chickpea *(Cicer arietinum* L.) could be traced, but it was reported that this crop is sensitive and that nodulation is poor under conditions of excess moisture (Argikar 1970).

Jackson (1979) investigated the short-term responses of peas to waterlogging under glasshouse conditions. The symptoms of injury arising from 1 to 4 days of waterlogging (during which the equilibrium pO_2 in the soil water fell to <1 kPa) included extensive desiccation and chlorosis of the foliage and lower rates of transpiration, stem extension, and growth of shoots and fruits. Flowering plants at the 9- to 10-leaf stage were more severely damaged than young plants bearing only 2 or 3 leaves. Similar conclusions were reached from waterlogging experiments with peas grown outdoors, in which shoot and seed dry weight were reduced by as much as 70% by 4 or 5 days' waterlogging (Cannell 1979; Belford et al. 1980). The effect of growth stage on the severity of waterlogging damage to peas is shown in Figure 5.

Relatively little investigation has been made regarding the flooding tolerance of forage legumes, but two studies by Heinrichs (1970, 1972) are noteworthy. He found that birdsfoot trefoil (*Lotus corniculatus)* was the most tolerant and sainfoin (*Onobrychis viciaefolia*) the least tolerant of the nine crops studied. Alfalfa (*Medicago media*) ranged midway between these two. Heinrichs (1972) also observed that birdsfoot trefoil was equally well able to survive at root-zone temperatures of 25, 19, and 13°C, whereas alfalfa and sainfoin improved in their resistance to damage as the temperature fell over this range.

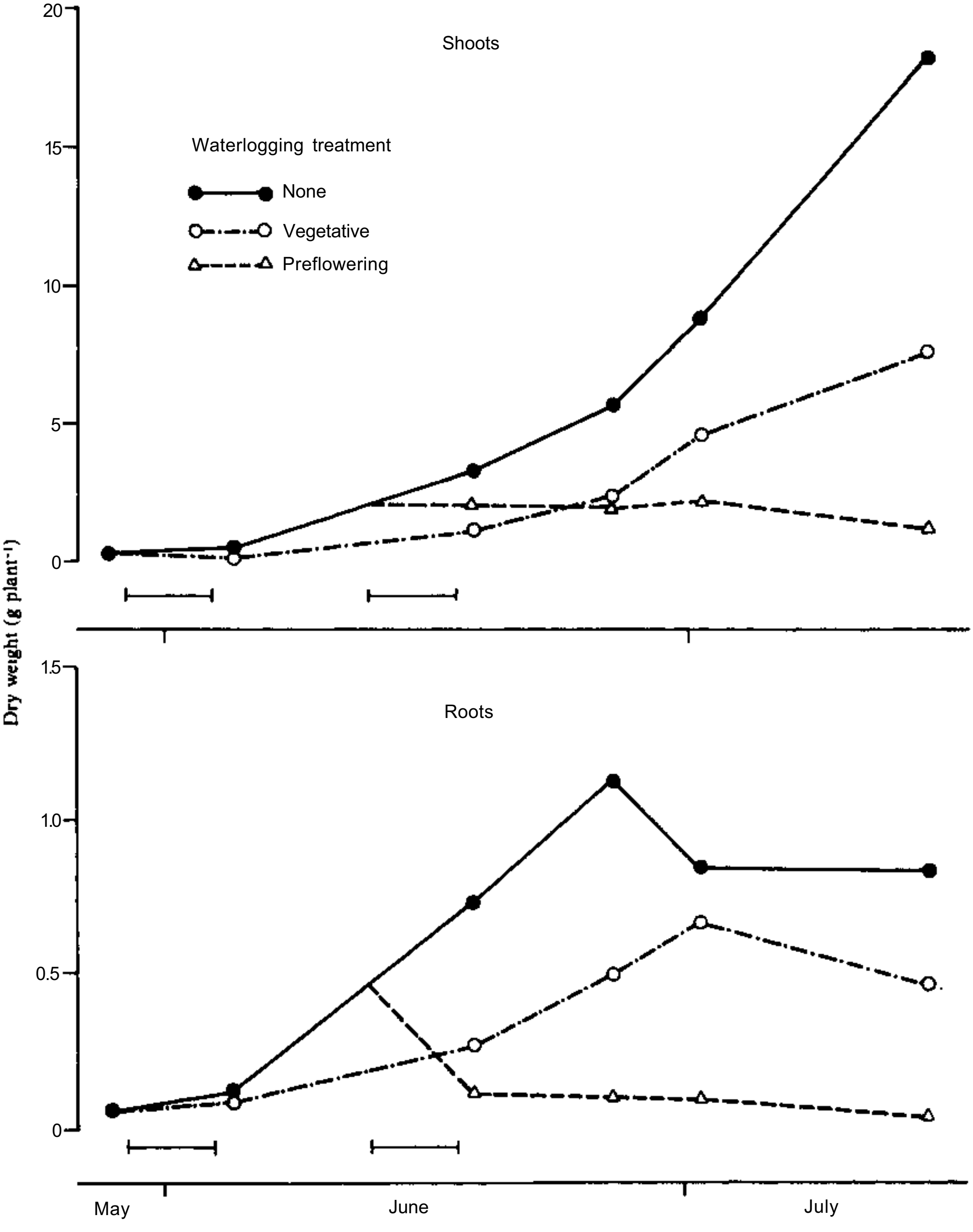

Figure 5. Change in dry weight of shoots and roots of peas grown in a sandy loam freely drained or waterlogged for 5 days during vegetative or preflowering stages of growth, indicated by horizontal bars. [Reproduced from R.Q. Canned, pp. 183-197 *in* Soil physical properties and crop production in the tropics (Lal, R., and Greenland, D.J., eds.) Copyright 1979, John Wiley & Sons Ltd. Reprinted by permission of John Wiley & Sons Ltd].

Root Nodulation and Nitrogen Fixation

There is evidence that the processes of root nodulation and nitrogen fixation by previously developed nodules are both more severely affected by waterlogging than are most other plant growth processes. Nodules require oxygen for the support of nitrogen fixation, and it was shown that with some species of legumes the optimum $p0_2$ is higher than the normal atmospheric concentration (Burris et al. 1955; Bergersen 1962). Relatively small deficits in oxygen produce large depressions of nitrogen fixation. Furthermore, the respiratory quotient (RQ) increases with declining $p0_2$, so that nitrogen fixation is much less efficient in terms of carbohydrate consumed at low oxygen tensions (Table 2). It was concluded that this effect has significant practical implication for nodulated legumes growing in waterlogged or consolidated, poorly structured soils (Bergersen 1971).

Much earlier, it was shown that the nodules of peas were much smaller than normal in nonaerated solution culture, and that plants grew poorly in the absence of combined nitrogen (Virtanen and von Hausen 1936). The plants grew well, however, when ammonium sulfate was supplied, thus demonstrating that the air requirement of the nodules, rather than the root system itself, was the more sensitive factor. In experiments with soybean, when $p0_2$ was reduced below the normal atmospheric level, it became limiting more quickly to the activities of nodulated root systems—which are dependent on the nodules (i.e., on symbiotic fixation) for nitrogenous compounds—than to those of nonnodulated root systems supplied with combined nitrogen (Bond 1950). This suggested that it was the response of the nodules (or of the bacteria) that chiefly governed the reaction of the plant as a whole to oxygen tension. Similar results were obtained for red clover (*Trifolium pratense* L.), although this species showed a greater response to oxygen than did soybean (Ferguson and Bond 1954).

Table 2. Relationship between $p0_2$, respiration, and nitrogen fixation by detached soybean nodules[1] (After Bergersen 1971).

	Respiration (mol gr^{-1} h^{-1})				
$p0_2$ (kPa)	0_2 uptake	CO_2 evolved	RQ	NH_3-N (molgr^{-1} h^{-1}	Ratio CO_2:NH_3
7.8	17.0	22.3	1.31	0.07	323
15.2	23.7	27.7	1.16	0.56	49.5
24.4	36.0	37.7	1.05	1.67	22.6

1. Freshly detached nodules produced on cv Shelby by strain CC 711 of *Rhizobium japonicum* incubated at 23° C in atmosphere containing 20 kPa $^{15}N_2$ and the pO_2 shown.

The nitrogenase activity of field-grown *Vicia faba* plants was measured by the acetylene reduction method, and it was found that activity declined significantly when water content exceeded field capacity and led to depressed aeration, as well as when the soil dried below field capacity (Sprent 1972). Later work under glasshouse conditions with a different cultivar, however, showed greater N fixation by plants under excess water conditions than by the controls (Gallacher and Sprent 1978). The same technique was used to measure the nitrogenase activity of peas in sand culture subjected to different water regimes (Minchin and Pate 1975). The results led them to state:

> ...The second conclusion of significance relates to the severity of the effects of waterlogging on symbiosis in sand culture. Nodule tissue production, the specific activity of the nitrogenase of the nodules, shoot nitrogen content, and percentage nitrogen in dry matter are all adversely affected, and in a manner indicating a specificity of symbiotic response unmatched by the effects of any other environmental influence studied... The steep decline in fixation activity below the water table of a flooded root and the finding that nitrate-fed roots are much less affected by waterlogging bear further witness to the specificity of the response.

Not all nodulated species are as severely affected as peas, and in the more flood-tolerant ones the nodules have the capacity to adapt to the poorer aeration in the root environment. One method of adaptation, which occurs in soybean (Pankhurst and Sprent 1975), cowpea (Minchin and Summerfield 1976), and *Vicia faba* (Gallacher and Sprent 1978), is the expansion of cortical cells to produce a more loosely packed nodule with interconnected gas-filled spaces that facilitate gaseous exchange. It has been shown that nodules with this open structure are more active nitrogen-fixers in a poorly aerated environment than the more compact nodules that

Table 3. Effect of (a) different concentrations of ethylene in open air systems and (b) the absorption of ethylene by chemical reagents from closed systems, on the nodulation of isolated *Phaseolus vulgaris* roots (After Grobelaar et al. 1971).

Treatment[1]	Mean (nodules/expt.)	Mean (lateral roots/expt.)	Mean dry mass (mg/expt.)
A. Open systems			
0 Pa C_2H_4 in air	35.3	84.7	41.4
0.04 Pa C_2H_4 in air	3.7	73.8	43.8
0.8 Pa C_2H_4 in air	0	41.6	33.8
30 Pa C_2H_4 in air	0	41.7	39.2
B. Closed systems			
Control (C_2H_4 not removed)	0	20.7	27.6
C_2H_4 removal by 0.01 N $KMnO_4$	8.7	47.6	34.5
C_2H_4 removal by 0.25 M $Hg(ClO_4)_2$	41.7	59.5	38.4

1. 1 Pa = 10 ppm (mg kg^{-1}).

develop under better-drained conditions (Sprent 1971; Criswell et al. 1976).

Another adaptation is the capacity fordenitrification, the ability to reduce nitrate to dinitrogen oxide and nitrogen under anaerobic conditions, and thus to use nitrate as an alternative electron acceptor to oxygen. The rhizobia that nodulate the relatively flood-tolerant cowpea are denitrifying organisms, whereas the rhizobia that nodulate the much less tolerant *Pisum sativum* are less able to denitrify (Zablotowicz et al. 1978).

The Possible Role of Ethylene

This paper has already considered the probable role of ethylene in affecting the sensitivity of plant roots to anaerobic soil conditions brought about by waterlogging. It is also possible that the processes of nodulation of legume roots by *Rhizobium* spp. and the fixation of nitrogen in nodules may be more sensitive to low concentrations of ethylene than many of the other plant physiological processes induced by this substance. Nodulation of bean *{Phaseolus vulgaris*) roots was reduced to only 10% of the control when the roots were exposed to trace concentrations of ethylene (0.04-1.0 Pa); the failure of roots to nodulate in closed containers could be completely overcome by circulating the air in the containers through mercury(II) perchlorate solution (Grobelaar et al. 1971)—an effective method of removing endogenous ethylene released by the roots (Table 3). In another experiment in closed containers, both the endogenous ethylene and ethylene applied at 1-10 Pa reduced the fixation of $^{15}N_2$ by more than 90% compared with treatments in which ethylene was continuously removed (Table 4). Nodulation of pea and white clover (*Trifolium repens* L.) plants was reduced more severely than shoot or root growth by exposure to 1 Pa ethylene; furthermore, the nitrogenase activity of those nodules that did form in the presence of ethylene was reduced by 90% in pea and 70% in clover over the controls (Goodlass and Smith 1979) (Table 5).

These observations, together with the indications that endogenous ethylene can inhibit the nitrogenase activity of subterranean clover (*Trifolium subterraneum* L.) (Day et al. 1975), demonstrate that both the nodulation process and the nitrogen fixation by existing nodules are generally very sensitive to ethylene. Furthermore, the required concentrations are well within the ranges observed (a) in soils where

Table 4. Effect of (a) initial addition of ethylene and (b) continuous removal of ethylene on the nitrogen fixation of nodulated *Phaseolus vulgaris* roots (After Grobelaar et al 1971).

Treatment	Atom % ^{15}N excess[1]
No C_2H_4 added or removed	0.716
1 Pa C_2H_4 added initially	0.946
10 Pa C_2H_4 added initially	0.626
C_2H_4 removed continuously	9.36

1. Nitrogen to which nodules exposed contained 72 atom % excess ^{15}N.

Table 5. Nitrogenase activity (C_2H_2 reduction) by nodulated roots of pea and clover following exposure of intact root systems to 1 Pa[1] of ethylene. (After Goodlass and Smith 1979.)

	C_2H_4 (ng nodule^{-1} min^{-1})		C_2H_4 (ng plant^{-1} min^{-1})	
Treatment	Pea	Clover	Pea	Clover
Control	0.036	0.44	1.44	6.29
Ethylene-treated	0.003	0.13	0.04	1.77

1. 1 Pa = 10 ppm (mg kg^{-1}).

aeration is impaired (Smith and Dowdell 1974) and (b) in roots as a result of endogenous formation when growing in inadequately aerated soil (Jackson and Drew 1984).

It is worth pointing out that waterlogging is only one example of an environmental stress that can induce the enhanced biosynthesis of endogenous ethylene. The same phenomenon occurs in beans *(Vicia faba)* subjected to drought and waterlogging (El-Beltagy and Hall 1974), and to physical impedance of root extension (Kays et al. 1974). Water stress also results in reduced nitrogenase activity (Sprent 1972), but it is difficult to assess whether this, too, may be directly associated with enhanced ethylene biosynthesis. In the case of waterlogging, the presence of a thick layer of water around each root and nodule reduces the escape of ethylene by diffusion, thus allowing its concentration to build up to physiologically significant levels; in very dry soils, conversely, physical conditions promote the diffusive loss of the gas from the roots.

Screening for Tolerance to Waterlogging

In principle, there are obvious advantages in screening plants for tolerance to waterlogging by directly comparing their growth and development in waterlogged soil, because no assumptions relating cause and effect need be made. Such a process is time-consuming, however, and it is extremely difficult to standardize conditions sufficiently to allow different experiments to be compared. For example, fluctuations in soil temperature or organic-matter content could affect the rate of development of anaerobic conditions.

An alternative may be to take account of the considerable evidence, briefly reviewed in this paper, that tolerance to waterlogging is intimately connected with hormonal changes in the plant—in particular the extent of accumulation of the gaseous hormone ethylene—and to make this the basis of a screening technique. Such a suggestion was made by El-Beltagy and Hall (1979), who compared two varieties of *Viciafaba* bean and found that the ethylene contents of aerial parts and roots increased over 9 days' waterlogging and that the variety with the greater concentration suffered considerably greater leaf abscission. They suggested that the measurement of endogenous ethylene production could possibly provide a technique for screening plants for relative tolerance to water stress.

There is other evidence, both of differences between varieties in the sensitivity of plant roots to exogenous ethylene (Smith and Robertson 1971) and of differences in endogenous ethylene production that may directly affect crop performance in the field. For example, the inhibition of hypocotyl elongation, which affected certain varieties of soybean, was due to rapid endogenous production of ethylene (Samimy 1970). Given that root nodulationand nitrogen fixation appear more sensitive to ethylene than other *plant* growth processes, it seems logical to further explore the possibility that determination of endogenous ethylene production and/ or sensitivity to exogenous ethylene may be employed as indicators of tolerance to waterlogging (and also possibly to other types of environmental stress).

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Soil Toxicities

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Screening for Tolerance to Salinity and Waterlogging: Case Studies with Pigeonpea and Chickpea

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Abstract

Areas where pigeonpea and chickpea are grown in India are prone to salinity and to waterlogging problems caused by irrigation, excess rainfall, and poor drainage. The area affected is increasing each year. Both crops are relatively sensitive to salinity and waterlogging stress. Improvement of salinity and waterlogging tolerance in these crops is desirable, not only to retain present areas of cultivation but also to extend cultivation into areas where salinity and waterlogging problems currently preclude it. Studies on a limited range of genotypes at ICRISAT and elsewhere have shown genotypic differences in both pigeonpea and chickpea for tolerance to soil salinity, and in pigeonpea for tolerance to short-term waterlogging. Some progress has been made at ICRISAT in developing field and laboratory screening methods to detect these differences. Several advanced breeding lines and cultivars with tolerance to soil salinity and short-term waterlogging have been identified. To identify even better sources of tolerance to salinity and waterlogging, there is a need to screen a much wider range of genetic material for both crops. Basic research to help understand the mechanism and inheritance of tolerance to both salinity and waterlogging is also desirable.

Introduction

Lack of water is one of the major factors limiting crop yields in the semi-arid tropics, and areas are being brought under irrigation to alleviate this stress. This approach to raising food production is unfortunately leading to problems of soil salinization and waterlogging (Rawlins 1981), both of which are inimical to plant growth and yield (Levitt 1980). High salt concentration in the soil solution lowers osmotic potential and reduces water availability to plants, and specific ions—such as sodium, chloride, and sulfate—can have toxic effects. Under waterlogged conditions, the anaerobic environment of the root zone affects plant metabolism, as well as nutrient and water uptake by roots. Thus, productivity of most agricultural crops is lowered.

A number of technological options have been suggested to contain salinity and waterlogging and to reclaim affected lands. Experts in these fields believe that while technological efforts must continue, they should be supplemented by genetically adapting crop plants to saline (Epstein 1978; Epstein et al. 1980; Rawlins 1981) and waterlogged environments (Krizek 1982). Genetic improvement in salt and waterlogging tolerance is possible, and good progress has been made in some crops. Salt-tolerant varieties of rice (Akbar and Yabuno 1974; Ponnamperuma 1977; Rana 1980), wheat and barley (Epstein et al. 1979), and tomato (Rush and Epstein 1976) have already been developed. Wheat (Yu et al. 1969) and pea (Jackson and Cannell 1979) cultivars tolerant to waterlogging have been identified. Genetic improvement of tolerance to salinity and

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waterlogging stress in both pigeonpea and chickpea, which often grow in these adverse environments, should also be attempted. This paper presents work on development of salinity and waterlogging tolerance in pigeonpea and chickpea.

Saline and Waterlogged Soils in Regions Growing Pigeonpea and Chickpea

Nearly 90% of the world's pigeonpea and 75% of its chickpea are grown in India; therefore the area under saline and waterlogged conditions in India highlights the magnitude of the problem. Areas under pigeonpea and chickpea in different states of India, as well as the extent of saline (Abrol and Bhumbla 1971)and waterlogged (National Commission on Agriculture 1976) soils in each state, are given in Table I.

In India 7 million ha of land is affected by salinity. Fairly large areas of the Indo-Gangetic plain, where pigeonpea and chickpea are grown, are saline. The saline areas in India are increasing; nearly 40000 ha of soils in India become saline every year (Raheja 1966). The principal salts in northern Indian saline soils are chlorides and sulfates of sodium whereas in southern Indian soils the major salts are chlorides and sulfates of sodium, and magnesium (Abrol and Bhumbla 1971). Although precise statistics are not available, nearly 6 million ha of land are considered waterlogged (see Table 1), which is nearly 10% of the total irrigated area (National Commission on Agriculture 1976). Of this, nearly 3.4 million ha are subject to surface flooding, mostly in the states of Uttar Pradesh, Gujarat, West Bengal, Punjab, Orissa, Andhra Pradesh, Kerala, and Tamil Nadu. The remaining 2.6 million ha have a high water table. Introduction of canal irrigation appears to be the major reason for the rise in the water table (Gupta 1980). By analyzing the climatic environment of pigeonpea, Reddy and Virmani (1981) found waterlogging to be a major constraint to its stabilized production during the rainy season, particularly on soils with high water-holding capacity. Indo-Gangetic alluvium and Vertisols are prone to waterlogging during the rainy season. Sinha (1981) also postulated that low yields of pigeonpea in some areas may be due to waterlogging. In chickpea, chances of surface flooding are small as it is grown in the postrainy season, but its production is adversely affected when the water table is within 0.9 m of the

Table 1. Distribution of saline and waterlogged soils and area ('000 ha) under pigeonpea and chickpea in India.

	Soils		Cultivated areas[3]	
State	Saline[1]	Waterlogged[2]	Pigeonpea	Chickpea
Uttar Pradesh	1295	810	516	1591
Gujarat	1214	484	228	88
West Bengal	850	1850	27	65
Rajasthan	728	348	31	1917
Punjab	688	1090	12	243
Maharashtra	534	111	706	461
Haryana	526	620	8	1440
Orissa	404	60	100	41
Karnataka	404	10	341	166
Madhya Pradesh	242	57	534	1932
Andhra Pradesh	24	339	248	46
Delhi	16	1	-	1
Kerala	16	61	3	-
Bihar	4	117	94	196
Tamil Nadu	4	18	125	16
Others	0	10	12	17
Total	6949	5986	2985	8220

1. Source: Abrol and Bhumbla (1971).
2. Source: National Commission on Agriculture (1976).
3. Source: Agricultural Situation in India (1982).

soil surface (National Commission on Agriculture 1976).

The extent of yield reduction in pigeonpea and chickpea due to salinity and waterlogging is not known, but it is expected to be substantial when the relative areas under these crops and the regions affected by salinity and waterlogging are considered. For example, at Haryana Agricultural University (HAU), Hisar, salinity has built up in the experimental fields as a result of a rise in the water table over the years. The production of pigeonpea and chickpea has been considerably affected. Certain patches in some fields have become so saline that neither crop can now grow, whereas their cultivation was possible a few years ago (N.P.Saxena, ICRISAT, personal communication). It is generally observed that areas where chickpea and pigeonpea production is declining correspond with regions where irrigation has been leading to increased problems of soil salinization and waterlogging.

Tolerance Limits of Pigeonpea and Chickpea

Soil Salinity

The effects of salinity on crops vary with stages of crop growth. It was observed that in solution culture there was a 50% decline in germination of 23 pigeonpea cultivars at 13 mmhos cm^{-1} EC, whereas a 50% reduction in seedling growth occurred at 9 mmhos cm^{-1} EC (Paliwal and Maliwal 1973). The salinity level required to reduce total dry matter (TDM) (ICRISAT, unpublished results) and yield (Promila and Kumar 1982) by 50% appeared to be 5 mmhos cm^{-1} EC of saturation extract (ESE). These studies also showed some cultivar differences. There are not many reports available of how these effects are mediated in pigeonpea. One study reported a decline in $^{14}CO_2$ uptake by pigeonpea in the presence of salts (Rao and Rao 1981). Another showed decreased rates of assimilate translocation under saline conditions (Deshpande and Nimbalkar 1982). Protein and nucleic acid metabolism was also affected under saline conditions, due to ion toxicity (Rao et al. 1981).

In chickpea, germination in solution culture was severely affected only when NaCl concentration exceeded 0.5% (Kheradnam and Ghorashy 1973). Chloride-dominant salinity was found to be more toxic to chickpea than sulfate salinity (Manchanda et al. 1981). Tissue chloride concentrations of 4.7% and above were found to be lethal for plant growth. Yield declined by 50% at an EC of 4 mmhos cm^{-1} ESE (Sharma et al. 1982). The response of chickpea to salinity seems to vary with moisture availability in the soil. Reductions in yield of chickpea under saline conditions probably occurred both as a result of osmotic and specific ion effects; a significant interaction of variety, salinity, and moisture level was observed for yield (Bharadwaj 1962). Ranking of cultivars for tolerance to salinity changed under stress and no stress situations.

Waterlogging

At ICRISAT Center, waterlogging in the rainy season often results in yellowing of the pigeonpea crop and then mortality, if waterlogging persists. Nearly 50% of the plant stand was lost when waterlogging persisted for 96 hours in a 40-day-old crop (1CR1-SAT, unpublished data); 40-day-old plants were more susceptible to waterlogging than 60-day-old plants. Plant mortality appeared to be related to a water deficit in the plants, which was probably caused by decreased water uptake by the roots. In some cases, it may also be due to phytophthora blight. Partial waterlogging may affect crop growth rates, as can be inferred from the fact that crop growth rates of pigeonpea during the rainy season are lower on Vertisols than on Alfisols. Further, yields of short-duration pigeonpea at ICRISAT Center, which matures at the end of the rainy season, are lower on Vertisols than on Alfisols, probably due to waterlogging on Vertisols. Pigeonpea planted on flat beds was relatively more prone to waterlogging during the July-August rainfall period than ridge-planted pigeonpea (Chowdhury and Bhatia 1971); it gave 23.6% lower yield than the ridge-planted pigeonpea, probably due to differences in waterlogging stress.

Waterlogging in chickpea (cv NP 58), which occurred 67 days after sowing, caused yellowing of young leaves and reddening of lower leaves (Saxena 1962). Root and shoot development were severely restricted and yield was reduced. Reduction in yield was 46% when the crop was subjected to 18 days of waterlogging, and 87% with 52 days of waterlogging. However, there was no plant mortality even with 52 days of waterlogging. (Such prolonged periods may be encountered in areas where water tables are high.) In addition, 12 days of waterlogging imposed 3 weeks after sowing resulted in a marked decline in dry weight and yield (Krishnamurthy et al. 1983).

Screening Methods to Identify Sources of Tolerance

Salt Tolerance *in* Pigeonpea

Pigeonpea is more sensitive to salinity than many other rainy-season crops, including maize and blackgram (Mehrotra and Gangwar 1964). Work at ICRISAT and elsewhere has shown that there are genotypic differences in tolerance to salinity in pigeonpea at different stages of growth (Paliwaland Maliwal 1973; ICRISAT 1977; Promila and Kumar 1982). Various criteria have been used by different workers to determine the relative tolerance of pigeonpea with respect to germination, survival, and yield potential in saline soils, as compared with non-saline soils. Paliwal and Maliwal (1973) screened 23 cultivars of pigeonpea for their salt tolerance characteristics, using NaCl and $CaCl_2$ salts in a 4:1 ratio. Both germination and seedling growth declined with increasing levels of salinity up to 18 mmhoscm^{-1} but cultivar differences were detected at both growth stages. A few cultivars were tolerant of salinity up to 9 mmhos cm^{-1}. Some cultivars, which showed less tolerance at the germination stage, appeared more tolerant at the seedling stage, and vice versa. Germination and seedling growth may be good parameters for rapid screening. This may also be relevant to the actual field situation: soil salinity levels are generally high at the beginning of the rainy season due to a capillary rise of salts during the preceding hot summer; later in the season the salts may be considerably diluted by rains. The use of yield-based criteria enables whole plant responses to be studied; however, it may not be very rapid and may not allow large numbers of genotypes to be processed. Promila and Kumar (1982) screened nine genotypes of pigeonpea for salinity tolerance in pots, using yield criteria. Some workers also used biochemical parameters such as protein and nucleic acid content to screen pigeonpea genotypes for salinity tolerance (Rao and Rao 1981). The utility of such methods for large-scale screening remains to be proven.

At ICRISAT the primary objective of studying salt tolerance has been to test commonly used cultiv-

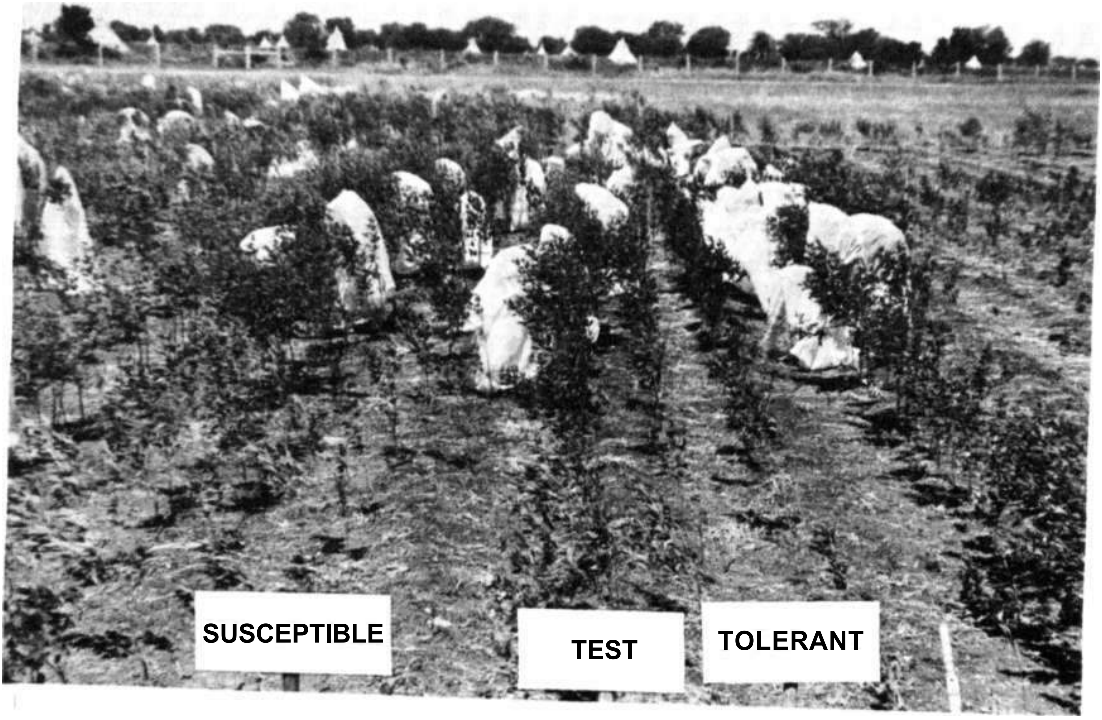

Figure 1. Screening for salinity toleranee in tha field. Pigeonpea cultivars C 11(tolerant) and HY 3C (susceptible) have been planted on either side of the test row.

ars and advanced breeding lines for various yield and resistance parameters. Both field and laboratory methods that allow detection of genotypic differences in pigeonpea and chickpea have been developed.

Field screening. Naturally saline fields are usually quite heterogeneous in their salinity levels, and therefore replicated plot tests have not proved useful. However, field planting of test lines in long rows, flanked on either side by known tolerant (C 11) and susceptible (HY 3C) cultivars, has proved quite satisfactory in determining the relative tolerance of test cultivars even under such heterogeneous soil salinity conditions (Fig. 1). The test lines were scored relative to adjacent tolerant and susceptible controls for survival at different stages of growth. Good differential responses were usually observed in moderately saline areas (about 6 mmhos cm^{-1} ESE), with much lower rates of survival in the susceptible control rows than in the tolerant rows. Genotypes surviving either better than or equal to tolerant controls were classified as tolerant. A number of advanced breeding lines and cultivars that survived better than the tolerant control, cvC 11, were identified using this method (Fig. 2).

This method could be improved further if a natural or artificially created gradient of salinity were available in the field. The genotypes could be planted along the gradient, and the length of surviving row could be treated as an index of the genotype's tolerance.

Screening in brick chambers. To test the performance of genotypes under more controlled conditions, a series of brick chambers ($1 \times 1 \times 1.5$ m) were constructed, with drainage taps at the base. The chambers were filled with black soil artificially salinized with various levels of a mixture of NaCl, Na_2SO_4 and $CaCl_2$ (7:1:2). At lower salt levels (40 milliequivalents kg^{-1} soil), clearcut differential responses between cultivars were observed. Genotypes C 11 and ICP 3786 showed tolerance and JA 275 and HY 3C showed susceptibility (ICRISAT 1977); this was in conformity with their behavior in saline fields. This method has limited utility, however, for large-scale screening.

Screening in pots. Field heterogeneity in salinity limits the number of lines that can be screened in any one season. To make a preliminary assessment of tolerance, a pot method was developed. The soil of the required conductivity (6 mmhos cm^{-1}, 1:2 soil water extract) was mixed in 1-kg capacity round plastic pots, which were maintained at field capacity after sowing. Differences in germination and seedling survival were noticed in less than a month. The differences in salinity tolerance obtained by this method were of the same order as previously obtained in the field. For example, C 11 was tolerant and HY 3C susceptible to salinity (Figs. 3,4). Using this method, a large number of genotypes could be screened within 1 month. A number of such screening cycles could be repeated within a year.

The preliminary screening of material in pots offers the possibility of salvaging surviving plants for producing pure seed of salinity-tolerant lines. Segregating lines, involving salinity-tolerant parents, can also probably be screened in this manner.

Salt Tolerance in Chickpea

Since chickpea is highly sensitive to salinity, the utility of yield-based criteria for identifying salt tolerance in chickpea has been doubted (Chandra 1980). Instead, preliminary evaluation at controlled salinity levels for response pattern was suggested. At 5.8 mmhos cm^{-1} ESE, a differential response among genotypes was observed. The performance of four chickpea cultivars in pots was compared using yield as a criterion, and genotypic differences were detected (Sharma et al. 1982).

Screening of chickpea cultivars on the basis of proline accumulation has given inconsistent results (Chandra 1980). Since interactions occur between salt tolerance and nitrogen source, selection of legume genotypes under both symbiotic and nitrogen-fed conditions has been thought desirable (Lauter et al. 1981)

At ICRISAT, the field, brick chamber, and pot screening methods earlier described for pigeonpea were employed also for screening chickpea cultivars. However, since chickpea is grown on residual soil moisture where moisture is often a limiting factor, it was felt desirable to carry out screening at two moisture levels. Interactions between response to salinity and moisture levels have been observed in a pot experiment (N.P. Saxena, ICRISAT, personal communication).

Waterlogging Tolerance

Little work has been reported on identifying waterlogging tolerance in pigeonpea and chickpea. At ICRISAT some screening capability has been deve-

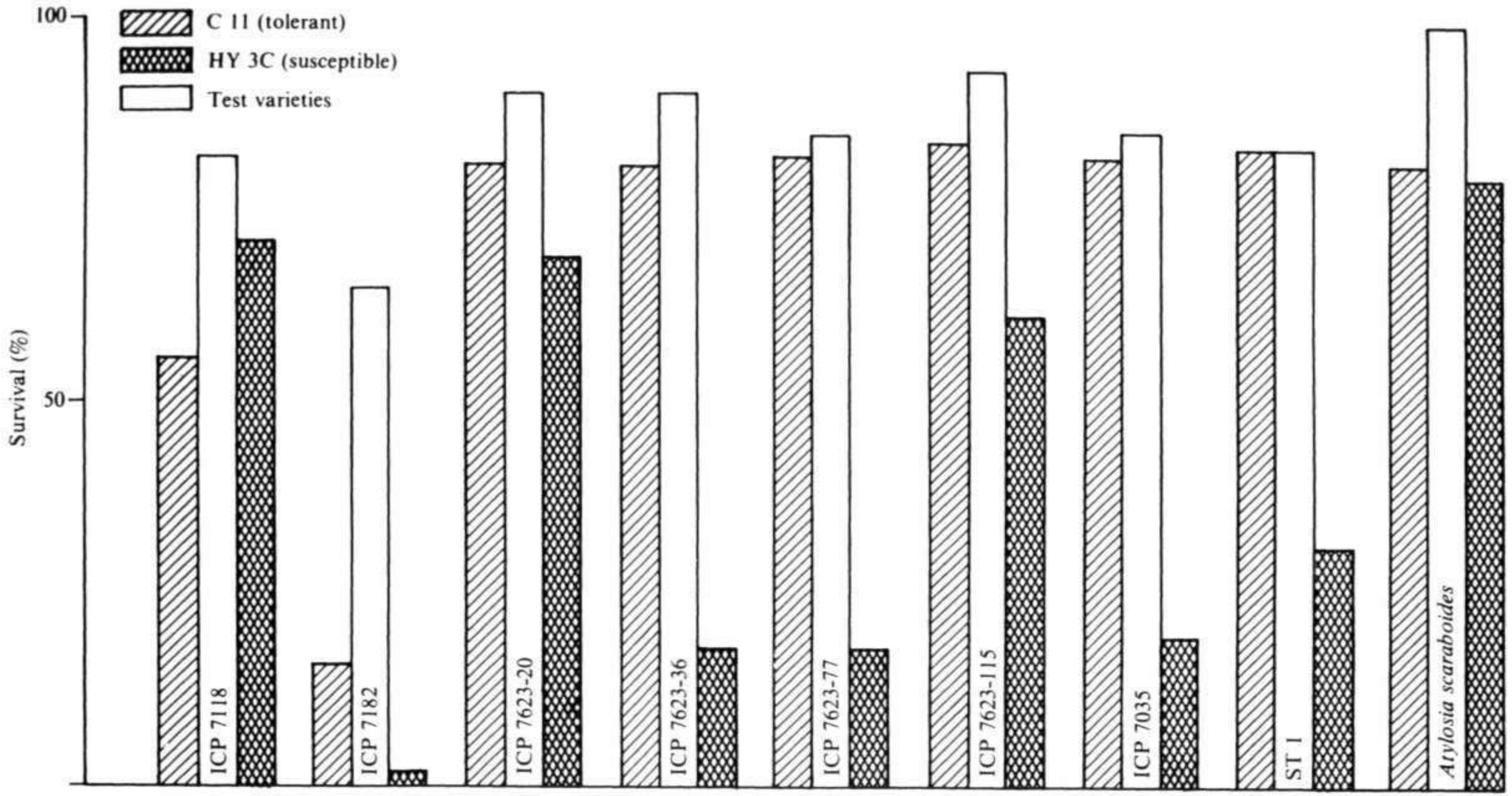

Figure 2. Screening for salinity tolerance in pigeonpea: percentage of survival in different pigeonpea test cultivars relative to tolerant (C 11) and susceptible (HY 3C) controls.

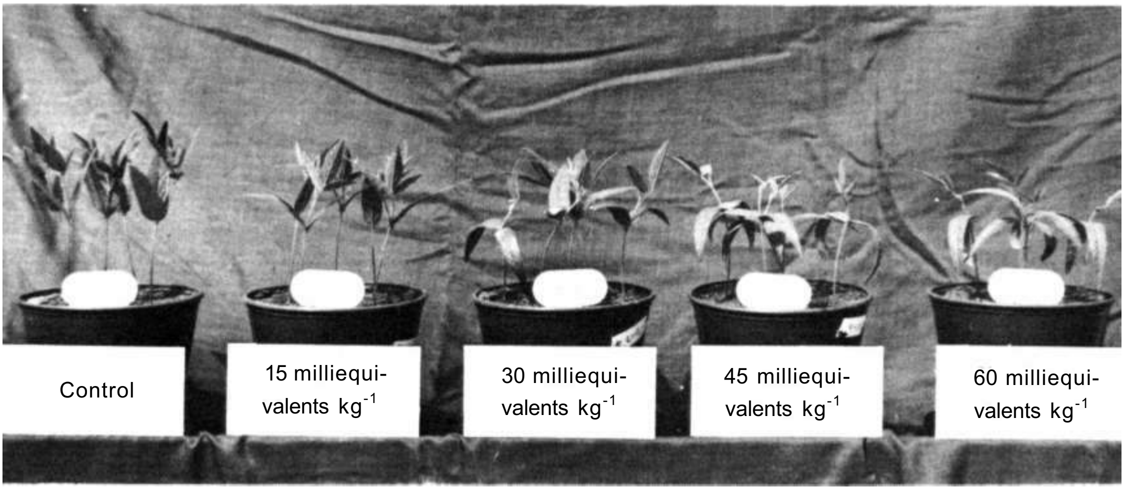

Figure 3. Effect of different levels of salinity on tolerant pigeonpea cultivar C 11.

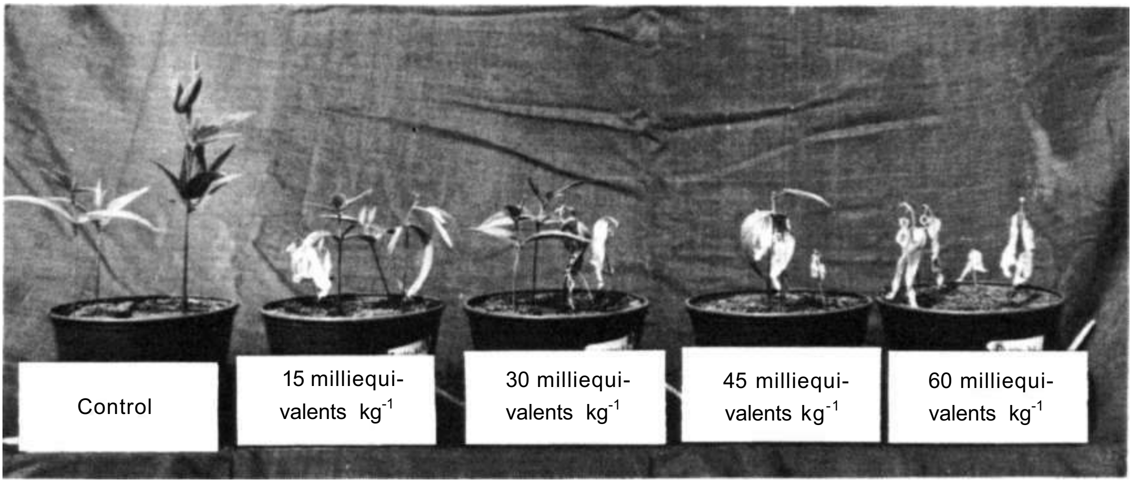

Figure 4. Effect of different levels of salinity on susceptible pigeonpea cultivar HY 3C.

loped to enable identification of tolerant cultivars. The screening criteria used are relative survival during and after waterlogging treatments.

Field Screening. On the basis of experience over several years, two pigeonpea cultivars, BDN 1 (tolerant) and HY 3C (susceptible), were selected. The screening procedure was similar to that used for salinity tolerance. These two cultivars were used as controls in field screening. The two controls were planted on either side of test rows in elevated paddy fields in which a tile drainage system had been installed (Fig. 5). The outlet from each set of tile drains had a stop cock that was used to control duration of waterlogging. The field was waterlogged for 4 days at 40 days after sowing. Response to this waterlogging stress in different cultivars was then recorded by counting the surviving plants.

Field screening thus carried out has several limitations. First, continuous cropping of pigeonpea in the same field encourages the buildup of phytophthora blight, which also kills plants under waterlogged conditions. Second, screening in the rainy season depends greatly on weather conditions. Under

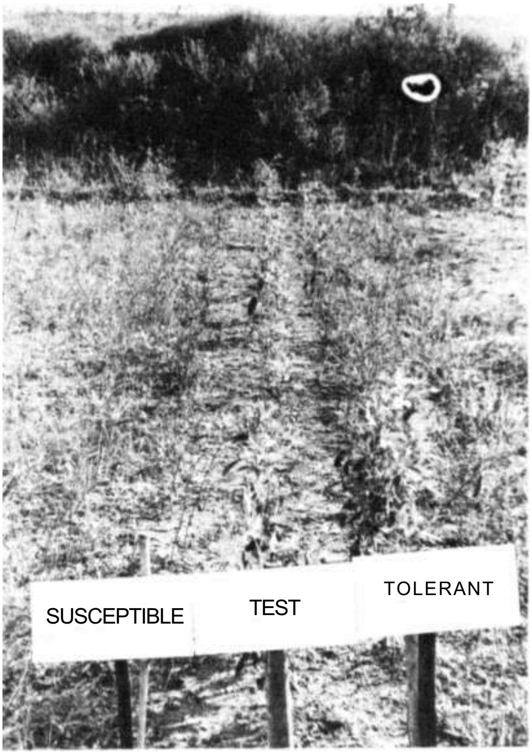

Figure 5. Screening for waterlogging tolerance in the field. Pigeonpea cultivars BON 1 (tolerant) and HY 3C (susceptible) have been planted on either side of test rows.

cloudy conditions, even several days of waterlogging may not result in plants wilting, probably because a transpiration lag does not develop. A transpiration lag due to decreased uptake of water by the roots under waterlogging is one reason for the mortality of waterlogged plants (Bradford and Yang 1981). Third, only a limited number of lines could be screened. Finally, release of waterlogging may not be uniform across the field, increasing the variability of recorded responses.

Screening in pots. A pot screening method was developed for efficient screening of waterlogging tolerance, to overcome some of the limitations mentioned. Since waterlogging effects were more pronounced in hot and clear weather, experiments were conducted in summer when ambient day temperatures were above 35°C. Pigeonpea lines to be tested were planted in plastic pots (18-cm diam) in May. The pots were perforated, lined at the bottom with muslin cloth, and filled with black soil. Five seedlings were raised in each pot, and they were allowed to grow under normal conditions until 40 days. They were then submerged in water-filled container pots for 5 or 6 days. The number of dead plants was recorded periodically after waterlogging was relieved. We recorded nearly 100% mortality in susceptible genotypes, whereas tolerant cv BDN 1 showed no appreciable mortality (Fig. 6). Phytophthora blight was avoided by using soil free of inocu-

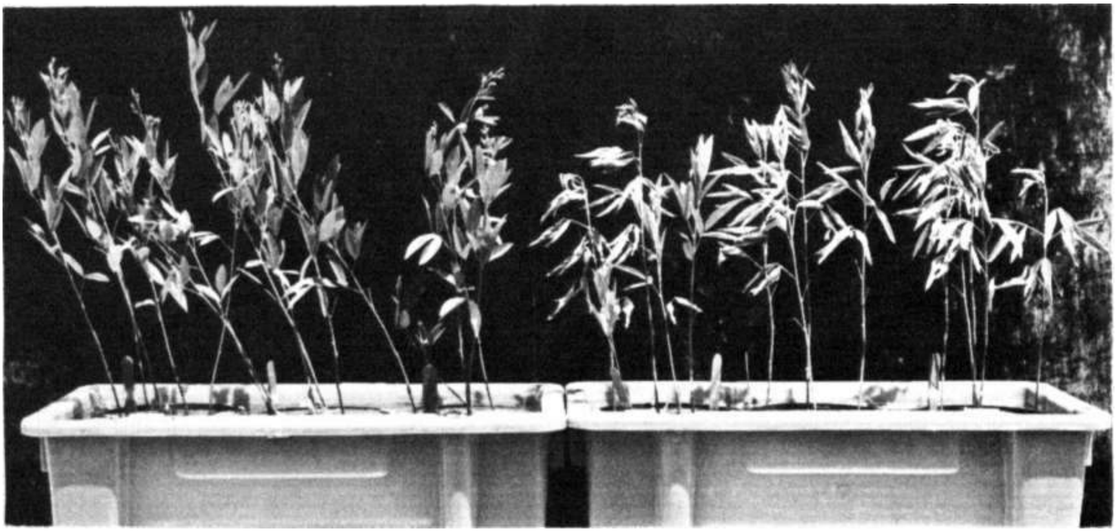

Figure 6. Screening for waterlogging tolerance in pots. Pigeonpea cultivar BDN 1 (left) shows no damage, while the susceptible HY 3C shows a large number of wilted leaves.

lum. A large number of lines could be screened using this method.

During standardization of this technique, interaction between soil collected from different Vertisol fields at ICRISAT and plant mortality due to waterlogging was observed (Fig. 7). In some soils, plant mortality in susceptible cultivars occurred within a few days after waterlogging, whereas in another soil fewer plants died. In waterlogged soil, microorganisms can produce ethylene (Lynch 1972). The amount of decomposable organic matter, which acts as a substrate for ethylene evolution, and the presence of these microorganisms need to be standardized to ensure uniform results. An indication of the role of these microorganisms was provided by the observation that in sterilized soil, even prolonged waterlogging did not cause appreciable mortality (Fig. 8). Further, greater mortality occurred in soil rich in organic matter.

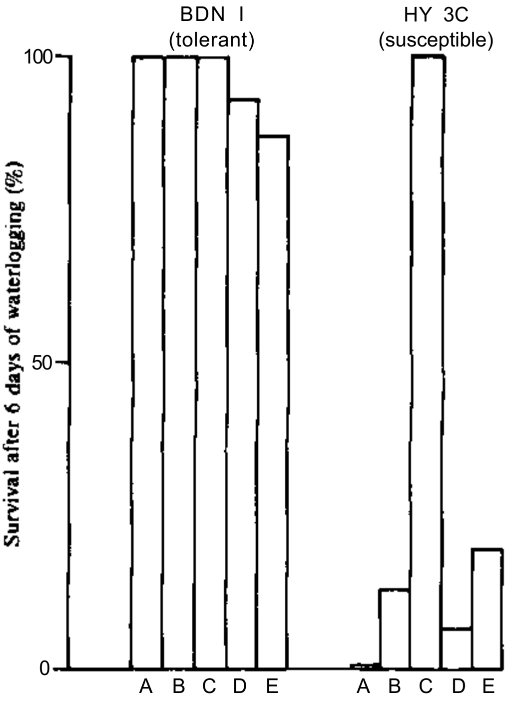

Figure 7. Percentage of survival after waterlogging of two pigeonpea cultivars (BDN 1 and HY 3C) in Vertisols collected from different fields at ICRISAT Center.

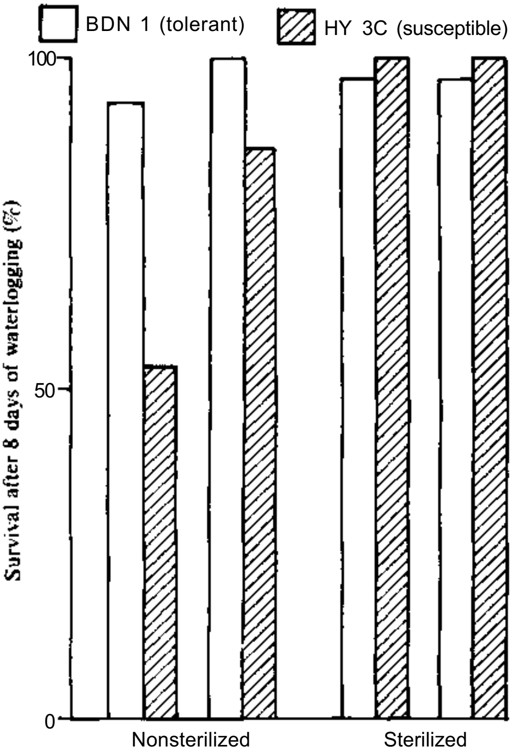

Figure 8. Percentage of survival of two pigeonpea cultivars (BDN 1 and HY 3C) in sterilized and nonsterilized Vertisols in pots at ICRISAT Center. Soil samples were collected from two spots, and results each are presented separately.

Combining Salinity and Waterlogging Tolerance

Salinity and waterlogging often occur together in irrigated lands. Thus, it would appear fruitful to combine salt and waterlogging tolerance in improved genotypes. While screening for waterlogging tolerance, we noticed some pigeonpea genotypes, such as ICPL 227, which possessed tolerance to both waterlogging and salinity. It would be worthwhile to intensify the search for genotypes with tolerance to both these stresses.

Future Needs

So far, only commonly grown cultivars and advanced breeding lines have been screened for tolerance to salinity and waterlogging in pigeonpea, and to salinity tolerance in chickpea. For identifying genotypes with greater tolerance, the genetic resources collection at ICRISAT needs to be systematically evaluated. It is likely that accessions originally collected from saline or waterlogged areas may have greater tolerance. These should be tested in steps for tolerance at various growth stages. Approaches using tissue culture techniques under saline conditions may also generate some variability for salinity tolerance (Rains 1981). Studies to understand the physiological and genetic nature of salt and waterlogging tolerance in known contrasting cultivars are also desirable. Further studies with both crops on the factors affecting salt and waterlogging tolerance are also necessary to evaluate and standardize procedures that can be used to select for different environments.

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Salt in the Soil Environment, and its Consequences for the Management of Chickpea and Pigeonpea

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Abstract

Chickpea and pigeonpea are well adapted to the harsh and nutrient-deficient environments in the semi-arid tropics. However, they have only a moderate tolerance to salinity, which may severely restrict their ability to perform well on marginally saline soils under dryland agriculture. The extent and types of salt-affected soils in South and Southeast Asia are discussed in relation to chickpea and pigeonpea production. It is argued that amelioration of saline soils under dryland agriculture will have a much less favorable benefit: cost ratio than amelioration of salinity in irrigated lands.

Introduction

Chickpea and pigeonpea are hardy crops that have adapted well to the harshness of the semi-arid tropical (SAT) environment. One example of their hardiness and adaptation is their ability to grow and mature in low-P status SAT soils, without the need for P inputs, when other crops such as sorghum and millet require moderate inputs (ICRISAT 1981). Another example is their ability to grow well in low-rainfall environments, provided the soil has a high available soil-moisture storage capacity. However, both crops appear to have only a moderate tolerance to salinity (Chandra 1980; Edwards 1981). We can therefore expect interactions between the moderate salt tolerance of these two crops and their hardiness in other respects. But to consider these interactions, we first need to know the types and extent of salt-affected soils in South and Southeast Asia.

It is estimated that in South and Southeast Asia an area of about 67 million ha is mildly to moderately affected with salt-related problems (Ponnamperuma and Bandyopadhya 1980). The majority of these problem soils are saline (49 million ha); the remainder are alkaline soils (12 million ha), or acid-sulfate soils (5 million ha). Saline soils are defined as those soils containing sufficient salts to reduce the growth of plants. Soils in the other two groups may not have a high salt content now but the effects of the original composition of the salts persist in the soil. In alkaline soils, the dominant cation is sodium, and the presence of carbonates and bicarbonates raises the pH to extremely high levels. Acid-sulfate soils are usually found after the intrusion of sea water; the reduction of sulfate causes extremely low soil reactions, resulting in high concentrations of ionic forms of iron and aluminum in the soil.

Within South and Southeast Asia, the location and causes of salinity may be grouped into the following classes (Ponnamperuma and Bandyopadhya 1980):

1. Low-lying coastal areas, where salt has accumulated in the soil from either periodic inundation by seawater or brackish water, or by upwelling of saline groundwater.
2. Inland areas, where salt accumulation came from (a) natural sources, such as wind-blown or rainfall-borne salt (cyclic salt) and poor drainage,

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or (b) anthropogenic causes, such as large irrigation schemes or localized irrigation with brackish water.

Saline soils of the low-lying coastal areas occur throughout the region, but inland saline soils are primarily located in India and Pakistan, where they extend over very substantial areas of the Indo-Gangetic plain in the former Punjab geographical area. Almost all the alkaline soils of the region are also located here. Less is known about the smaller areas of upland soils that are saline or salt-affected, despite the importance of salinity for pulse crops under rainfed conditions; it is only recently that attention has been given to upland soils, as for example in peninsular India (CSSRI 1979). Past salinity research has concentrated on the coastal low-lying soils for paddy rice production (Ponnamperuma and Bandyopadhya 1980), and on the inland soils of the large irrigation schemes in the Indus and Ganges valleys (Kanwar 1980).

Physical and Chemical Environment of Salt-Affected Soils

Saline soils are flocculated because of the high concentrations of salts in the soil solution. The salt concentration affects plant growth directly as well as indirectly; the high osmotic pressure reduces uptake of water; and the different ionic compositions in the soil solution (compared to "normal" soils) may markedly affect the availability and uptake of nutrients by plants.

In most saline soils of this region, sodium is the dominant ion. Lowering of the salt content of the soil by leaching, either naturally by rainfall or with good-quality (low-salt) water„does not eliminate the problems caused by salt. This is because as the salt concentration in the soil solution is reduced, the clay will disperse when even a small proportion of its exchange sites (<7-15%) are occupied by sodium, (Northcote 1971; USDA 1973). The low permeability of sodium-dominated soil hinders further removal of salts and also promotes waterlogging.

The formation of carbonates and bicarbonates of sodium leads to extremely high soil reactions, with pH values of 9 and 10 not uncommon, and this adversely affects the availability of some mineral nutrients, such as Fe and Zn. When removal of salt by leaching is attempted, gypsum may be essential to provide both a source of calcium (to ensure calcium dominance of the exchange cations on the clay surfaces) and a noninjurious salt in solution (to minimize dispersion of the clay).

Similarly, in acid-sulfate soils, the extremely low pH creates a very poor medium for plant growth, because of the low pH per se, as well as associated high Al, Mn, and Fe ion concentrations. Acid-sulfate soils have variable soil physical conditions, depending on soil water regime and Al and Fe salts present. However, they usually have a poor physical condition, with poor aeration when wet or waterlogged.

Management of Salt-Affected or Salinity-Prone Soils

Reclamation of saline-alkaline soils by leaching and gypsum application leads to two major causes for concern in subsistence agriculture. First, the ameliorants involved are bulky, and large amounts are involved; unless supplies are available nearby, the costs will be high. Second, in many situations, the propensity of a soil to develop a salinity-related problem can be predicted in advance; the cure may be much more difficult than prevention because leaching for removal of salt or for changing the balance of adsorbed cations will become much more difficult when the whole profile has become alkaline affected.

A soil may have a good permeability before salinity-related problems develop. However, once an appreciable proportion of the cation-exchange sites become occupied by sodium, any attempt to leach salt through the soil will cause dispersion and a decrease in permeability to negligible rates. For heavy-textured alkaline soils, the addition of gypsum to the soil surface will cause improved permeability only in the surface layer. Deep leaching through the profile will be prevented by sodium clay at depth, but calcium in gypsum can readily replace that sodium only with adequate leaching. Clearly, the best solution is to prevent the development of sodium-affected clays throughout the profile; ideally, gypsum should be added as soon as a potential saline-alkaline problem is recognized and before the problem becomes severe.

Provision of drainage systems will be necessary in many saline soils for removal of water and salt from depth in the profile. Only in the better-textured soils, e.g., the Entisols of the Indo-Gangetic plain, are the costs of drainage provision likely to be minimal. On these, widely spaced tube wells to pump any water will be adequate. On the heavier textured soils, however, the solution is more difficult; the poor lateral drainage in these soils means that closely spaced tile-drains may be essential for reclamation. Such drainage costs are extremely high, and the best solution is to concentrate on minimizing development of salt problems.

The costs of attempting any amelioration of soil under rainfed agriculture will be much higher than under irrigation. Restoration of the soil, with adequate availability of water, will depend on the soil's permeability. However, under rainfed agriculture, only a small proportion of the rainfall moves through the profile, even with optimum soil permeability. With permeability restricted, leaching will be much less and the restorative process will take much longer than under irrigation. Restoration of heavy-textured soils is slow under irrigated agriculture; it will be extremely slow under rainfed agriculture. Additionally, the benefits of reclamation are greater in irrigated agriculture, where potential productivity is greater than in rainfed agriculture. When these factors—the speed of restoration and potential productivity—are considered, the benefitxost ratio of restoring rainfed land will be much lower than that for irrigated land. Again, prevention is better than cure.

During restoration, a gradually increasing depth of surface soil becomes free from the effects of salt and alkali (or acid sulfate) influences. Plant roots can explore this restored depth easily but will be deterred from deeper exploration because of the hostile soil environment caused by salinity at depth. Such restriction of rooting depth will effectively decrease the amount of water in the soil accessible to a crop. This consequence of the adverse environment at lower soil depths is less of a disadvantage for irrigated crops, because an increase in frequency of irrigation can compensate for the lower effective amount of available soil water. In rainfed crops, however, restriction of the soil volume explored by roots could be crucial in determining the success or failure of a crop, especially deep-rooting crops such as chickpea and medium-and long-duration pigeonpea. Both crops make much of their growth in the postrainy season and depend upon full exploration of the soil profile for their water supplies. Clearly, any restriction on rooting depth, such as salinity, will jeopardize the crop.

In the past, the low-lying soils in coastal India have been used predominantly for paddy rice; recently, interest has developed ingrowing pulses. In other areas, especially inland soils, pulses are commonly grown under upland (nonirrigated) conditions both in soils that are commonly irrigated as well as in those traditionally used only for rainfed agriculture. For these groups of soils, the strategy for handling salts will differ. For the irrigable soils in the coastal low-lying region and the inland Indo-Gangetic plain, amelioration can be relatively easy. The requirements are an excess of water to flush excess salts through the soil and treatment with calcium salts (usually gypsum) to keep the proportion of sodium on the cation-exchange sites to < 15% (the critical value above which the soil disperses). For inland upland soils under rainfed agriculture, such as the Vertisols of the Deccan on which chickpea and pigeonpea are useful postrainy-season crops, amelioration is much more difficult; under natural rainfall, the rate of leaching will be much lower and the cost of calcium salts (or gypsum) will be less affordable for the farmer because his forseeable profits are lower in rainfed than in irrigated agriculture.

While it is tempting to consider the use of salt-tolerant cultivars, these can only offer a palliative. If the soil is likely to develop a salinity problem, corrective measures must be taken; and for rainfed crops, this must be done early because the restorative process is slow once the soil becomes saline.

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Mechanisms of Salt Tolerance and their Relevance

C. Johansen[1]

Abstract

The consequences of high levels of salinity in the external medium on growth and metabolism of higher plants are briefly outlined. Mechanisms evolved to cope with saline environments are then discussed. Salt-tolerant plants can be broadly classified as either salt excluders or salt accumulators. The salt accumulators can either tolerate high intracellular salt levels or are able to remove excess salt accumulation from sensitive cellular compartments or tissues. It is suggested that the mechanistic basis of salt tolerance be determined for chickpea and pigeonpea to enhance screening procedures for salt tolerance. The mechanistic approach to screening is to be preferred over relying on empirical methods of screening by growing genotypes at a range of salt levels.

Introduction

This brief discussion paper first considers the range of mechanisms available to higher plants for coping with saline environments and then suggests how this knowledge may be applied to detect salt-tolerant genotypes of chickpea and pigeonpea. In the following paper, Dr N.P. Saxena will more specifically consider how to go about genetically improving salt tolerance in these plants.

In screening and breeding for disease resistance, it is necessary to pinpoint the causal organism and understand how it affects plant growth and function. The pulse pathology work at ICRISAT bears witness to this. Like disease, salinity covers a multitude of causal factors and responses, and, in identifying tolerance, it is necessary to pinpoint causal factors, such as general osmotic effects or specific ion effects, and to understand what possible mechanisms certain plants have of coping with excess salt. This is self-evident, but it is worth emphasizing because many experimenters attempting to identify salt-tolerant genotypes do not seem too concerned about the mechanisms involved. Of course, we could continue to screen genotypes at graded salt levels to pick up differences in response, but knowledge of the mechanisms of salt tolerance operating in our test crops would help streamline the screening process.

The following presentation of salt effects on plants is based largely on the concepts propounded by a former colleague at the University of Western Australia, Dr Henk Greenway (e.g., Greenway 1973; Greenway and Munns 1980; Munns et al. 1983). Further, more detailed discussion of the points raised may be found in the reviews of Levitt (1980, pp. 365-88) and Wainwright (1981).

Major Types of Plant Response to Salinity

Most physiological studies on plant response to salinity have used NaCl as the test salt, and relatively little is known about the physiological consequences of alkalinity/sodicity. Figure 1 indicates a broad classification of higher plants in their response to NaCl in the external medium. Certainly chickpea and possibly pigeonpea would belong to the salt-sensitive group.

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[1] Legumes Program, ICRISAT.

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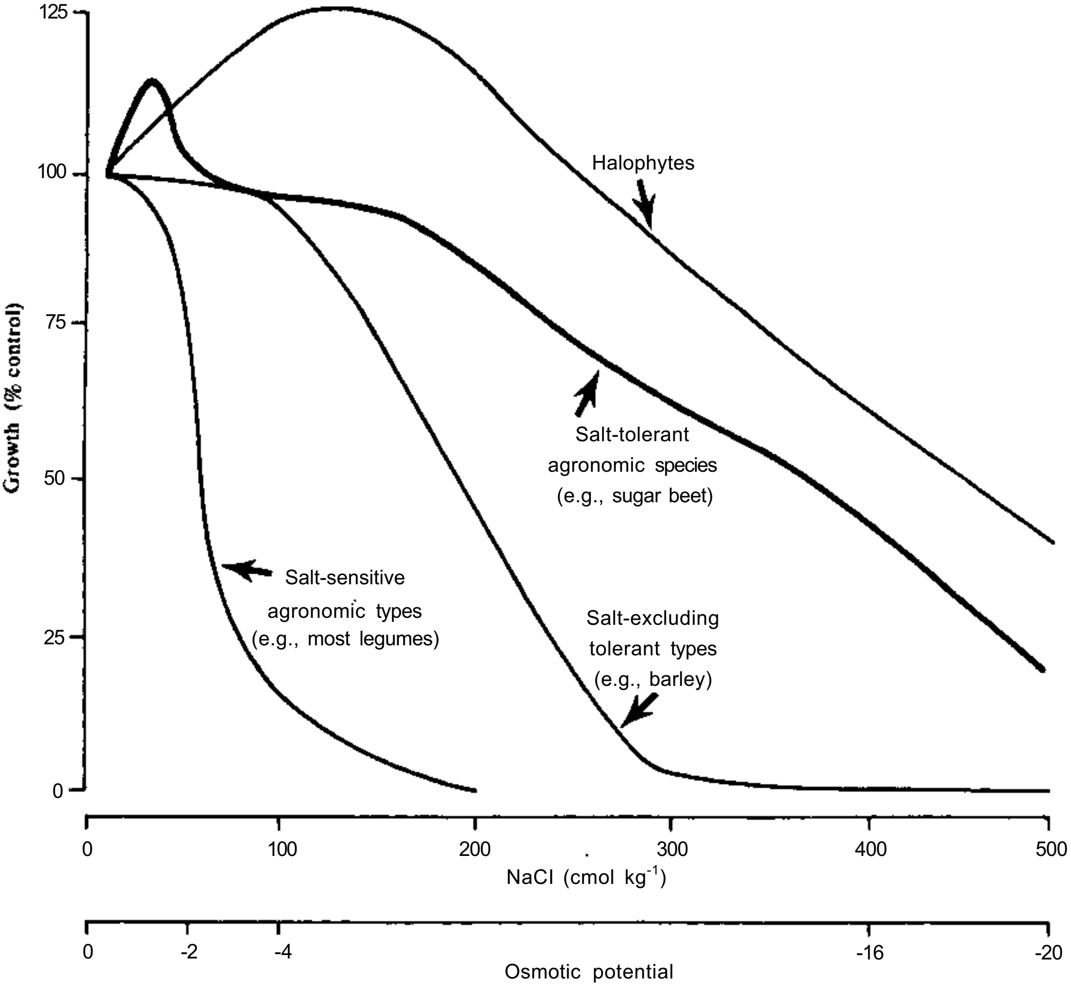

Figure 1. Responses of various categories of higher plants to NaCl salinity. (After Green way 1973.)

Effect of Salinity on Physiological Processes

The consequences of having high salt concentrations in the soil solution are illustrated in Figure 2. Plants growing in a saline environment may be affected by the lower water potential in the environment and plant cells, causing reduced salt uptake, or by increased salt uptake caused by high external ion concentrations. Plants may adjust to this situation by accumulating organic solutes where salt uptake is reduced, or by controlling high levels of salt uptake, so that plant cells osmotically adjust to the external environment and thus maintain high turgor. However, plant growth is reduced where cell turgor cannot be maintained or where internal salt concentrations become toxic to the normal cell metabolism. These toxic effects can manifest themselves as microosmotic effects between adjacent cells or cell organelles, interference with enzyme systems and other metabolic functions, and competition of "salt" ions with nutrient ions in active transport across cell membranes.

Figure 2. Effects of salinity on various plant physiological processes. (After Greenway 1973.)

Mechanisms of Salt Tolerance

Different higher plants have evolved various mechanisms to cope with a saline environment. These may be summarized as follows.

Salt Excluders

Such plants have an enhanced ability to exclude salt, either from the entire plant or from particular organs. This is accomplished by cell membranes with high ion selectivity, favoring potassium over sodium for example. Examples *of* such plants include barley, citrus, and soybean. Such plants become particularly prone to moisture deficits under saline conditions, however, and they must rely on organic ion production for osmotic adjustment. This has a high metabolic cost, and overall plant growth rate can be markedly retarded whenever the osmotic imbalance is large. These types of plants are characterized by low sodium and chloride levels in plant tissues.

Salt Accumulators

Such plants are able to cope with a high uptake of salt in several possible ways, some of which are outlined below.

Tolerance of high intracellular salt levels. This includes the group of plants termed "halophytes" and also some plants of agricultural importance, such as sugarbeet. In these plants, cell metabolism is relatively unimpaired by high internal salt concentrations and plant tissues have high Na/K ratios. Indeed, as in sugarbeet and *Atriplex* spp, sodium may substitute for potassium as a plant nutrient. This property allows rapid osmotic adjustment to external saline conditions with a minimal cost of metabolic energy; there is not so much reliance on organic ions for osmotic adjustment. However, this method can lead to specific ion toxicities and mineral imbalances if external salt concentrations become too high.

Removal of excess salt accumulation. By this mechanism plant roots are able to freely take up excess salt, but damaging intracellular accumulation of salt is avoided by:

1. Compartmentation of salts into various plant components, such as vacuoles (as in barley) or stems (as in broad beans);
2. Extrusion of salt from the plant surface by salt glands (as in *Atriplex* spp);
3. Succulence, which is the ability of plants to vastly increase cell volume with water to maintain an appropriate osmotic potential (as in cactus).

Mechanisms Applicable to Chickpea and Pigeonpea

When we consider the salinity response of the entire higher plant kingdom, chickpea and pigeonpea are found comparatively sensitive to saline conditions, with chickpea particularly so. Studies at ICRISAT and elsewhere have indicated, however, genotypic differences in response to salinity within these crop species (Saxena 1984; Y.S. Chauhan, ICRISAT, personal communication). The screening process could be streamlined if we knew the mechanistic basis for these differences. For example, if it is determined that more-tolerant types have an ability to exclude sodium, then chemical analysis of the Na/ K ratio of a wide range of genotypes grown and sampled under similar conditions might be a more effective screening procedure than the currently used empirical method of growing plants at graded levels of salinized soil. It should also be noted that chickpea has a particular capacity to produce and exude malic acid from leaf surfaces (Saxena 1984). This process would no doubt have considerable osmotic consequences on leaf cells and may thus be related to the response of chickpea to excess salt accumulation. However, without indulging in any further speculation, I would suggest that a concerted effort be made to identify mechanistic differences between genotypes of chickpea and pigeonpea in coping with excess salt, rather than simply proceeding with the traditional, empirical methods of screening for salt tolerance.

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Problems and Prospects to Screen and Breed for Tolerance to Soil Salinity: A Case Study with Chickpea

N.P. Saxena[1]

Abstract

It is imperative that tolerance of crop species to soil salinity be improved because salinization of agricultural soils will continue to occur. Recognizing the limits to which salts can be tolerated in a given crop species, such as chickpea, and the variability that is available in the germplasm, it should be possible to screen a large number of genotypes for this trait, both in pots and in the field. This should allow identification of material that can immediately be used as cultivars or as parents in a breeding program. This paper suggests how heterogeneous soil salinity under natural conditions can be used in field screening of genotypes for salinity tolerance. It proposes methods for advancing breeding material and for testing the end product in a program to breed chickpea cultivars with increased salinity tolerance; the approach may also be applicable to pigeonpea.

Introduction

The papers presented at this workshop point to the increasing threat to crop productivity from salinization of agricultural soils. Lands that previously were productive have had to be abandoned for cultivation due to this menace, which is associated with the introduction of irrigation in many countries in recent years (Abrol and Bhumbla 1971; Mohammed 1976, cited in Wyn Jones 1981; Ponnamperuma 1977). To return these lands to cultivation and to retard or prevent loss of further land to salinity, two options are available: (1) reclamation of salt-affected soils, and (2) crop selection or genetic improvement within a crop species for salt tolerance.

The traditional approach of reclaiming saline and sodic soils, though difficult in terms of time and money required, has been very effective and widely recommended (USDA 1973). It has produced encouraging results in India, Israel, Pakistan, the United States, and many other countries. Although it is possible to restore the soil's full agricultural potential when other factors do not limit productivity, reclamation is often constrained by various geographical problems. For example, in parts of California, USA, and Haryana, India, it has not been possible to adequately drain saline subsoil water.

The second option of living with the salts seems to have become increasingly necessary. Earlier, selection of crop species for cultivation on saline soils was considered not very useful or promising (Hilgard 1906, cited in USDA 1973). That it is practicable to select for salt tolerance was indicated in work with tomato (Lyon 1941); this possibility was later demonstrated with the selection of a highly salt-tolerant barley cultivar that could be grown with irrigation using sea water (Epstein and Norlyn 1977).

The role of tolerance to soil salinity in increasing and stabilizing crop productivity should not be overplayed, however. It is unrealistic to expect resistance to salinity in crop plants in the same way that resistance to biotic stresses of diseases and pests has been achieved. One has to accept that there are limits to the tolerance of excess salts in the soil by different crop species. Within a given crop species, although

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there might be a large genetic diversity for various traits, there may only be a narrow range of genotypic differences in tolerance to salts.

The Salinity Problem

Salinity occurs in heterogeneous patches (Abrol and Bhumbla 1971; Chandra 1980), and the ionic composition of salts varies from place to place. For example, the saline-alkaline soils in Haryana, Punjab, Rajasthan, and Uttar Pradesh have a predominance of sodium; saline soils in southern parts of India have chlorides and sulfates of sodium with large quantities of $CaCO_3$; and saline soils of West Bengal have a predominance of magnesium (Abrol and Bhumbla 1971). This variability in ionic composition of salts in saline environments seriously constrains selection and breeding of genotypes with a wider adaptability across locations. Further, the reaction of species or cultivars for tolerance to salts is not a definite feature of a cultivar since it changes with atmospheric factors, such as humidity (Hoffman and Jobes 1978) or temperature.

Because of the heterogeneous occurrence of salinity in the field, it is not considered possible to study responses to soil salinity under field conditions (Chandra 1980). Also, since chickpea is sensitive to salinity, it has been suggested that it may not be possible to make use of yield-based criteria in this crop (Chandra 1980). But as our primary concern is productivity in saline environments, it is necessary that only yield-based criteria are used, rather than indirect indices of yield performance.

Poor Plant Stands

The occurrence of poor plant stands is a common feature in saline fields, and this inevitably reduces yield. Differences between crop species in germination under saline environments are well known (Mehrotra and Gangawar 1964; USDA 1973), and variability within crop species has been noted for pigeonpea and chickpea in artificially salinized soil. Seeds of genotypes better able to germinate in saline environments would be very useful in improving plant stands and thereby contributing to increased and stable yields. Genotypic differences in tolerance of different ionic species are also of practical importance, in view of the differences in the types of salts in saline soils and the modifying influences of other accompanying ions, such as calcium.

Tolerance to Salinity

Criteria for Selection

Visual Criteria

In saline environments, chickpea exhibits development of distinct symptoms, such as the appearance of anthocyanin pigments on the foliage in the desi cultivars and the characteristic yellowing of the foliage in the kabuli types. In a moderately saline environment, which does not cause plant mortality or a severe reduction in growth, relative genotypic differences can be detected under field conditions by observation of symptoms. Such differences are not so visible in pigeonpea, however.

Relative Biomass and Yield Reduction

Two different weight-based criteria have been described to determine genotypic differences in salt tolerance (Chandra 1980):

1. the level of soil salinity that would bring about a 50% reduction in shoot weight or seed yield; and
2. relative decline in biomass or yield with increasing levels of soil salinity (slope of the response curve).

Screening Methods

Field Method

As pointed out earlier, heterogeneity of soil salinity is a discouraging factor in developing field screening methods; therefore, pot methods, using artificially salinized soils, are recommended (Chandra 1980). At ICRISAT we are trying to use the natural occurrence of heterogeneous soil salinity to our advantage. The procedure followed is to grow each chickpea genotype in a long row across a moderately saline field, passing through the heterogeneous patches of salinity (Fig. 1). A test line in a row is flanked by a tolerant and a susceptible control. The genotypic differences in salinity can be scored in two different ways: visually, and by relative decline in plant biomass and yield.

1. Visual scoring. Genotypes are scored on a 1-9 scale for severity of foliar symptoms due to soil salinity, in relation to tolerant and susceptible con-

Figure 1. A field method of screening chickpea for genotypic differences in tolerance to soil salinity.

trols. The scale used is as follows:

1 = No symptoms visible
3 = Symptoms visible on older leaves, but plant apparently normal
5 = Symptoms visible on all leaves, but plants can produce pods
7 = Severe symptoms (burning and scorching)
9 = Susceptible (plants dead)

Table 1. Genotypic variation in chickpea of intercepts (potential dry matter), slopes (tolerance to increasing levels of salinity), and EC (electrical conductivity) levels that bring about a 50% reduction in dry matter (n = 32).

Genotypic variation	Intercepts	Slopes	EC for a 50% reduction in total dry matter
Minimum	0.38	-0.17	1.19
Maximum	0.99	-0.05	2.95
Mean	0.60	-0.10	1.68
SE±	0.019	0.003	0.059
Variance	0.011	0.0004	0.110
Standard deviation	0.107	0.020	0.331
CV (%)	17.9	20.7	19.7

In studies to date, genotypes exhibit distinct differences in reaction to salinity, and genotypes with a greater degree of tolerance in the field (e.g., L 550) also prove to be tolerant in greenhouse tests.

2. Relative decline in plant biomass and yield. The relative decline in biomass and yield of genotypes is also determined by recording dry matter and yield at a number of positions along the line where growth differs. Soil samples are taken from these areas to determine the salinity (electrical conductivity, EC) level. Yield and biomass are then regressed against salinity level to determine:

a. relative differences in slopes in dry matter and yield with increasing levels of salinity (EC) among genotypes; and
b. differences among genotypes for the level of salinity that would bring about a 50% reduction in yield.

This method is very laborious, however, and may not be practical on a large scale.

Greenhouse Method

The above regression approach was tested in pots in a greenhouse, using graded levels of soil salinity and maintaining the soil moisture around field capacity. The crop was harvested 40 days after sowing, and the biomass was regressed against the graded levels of

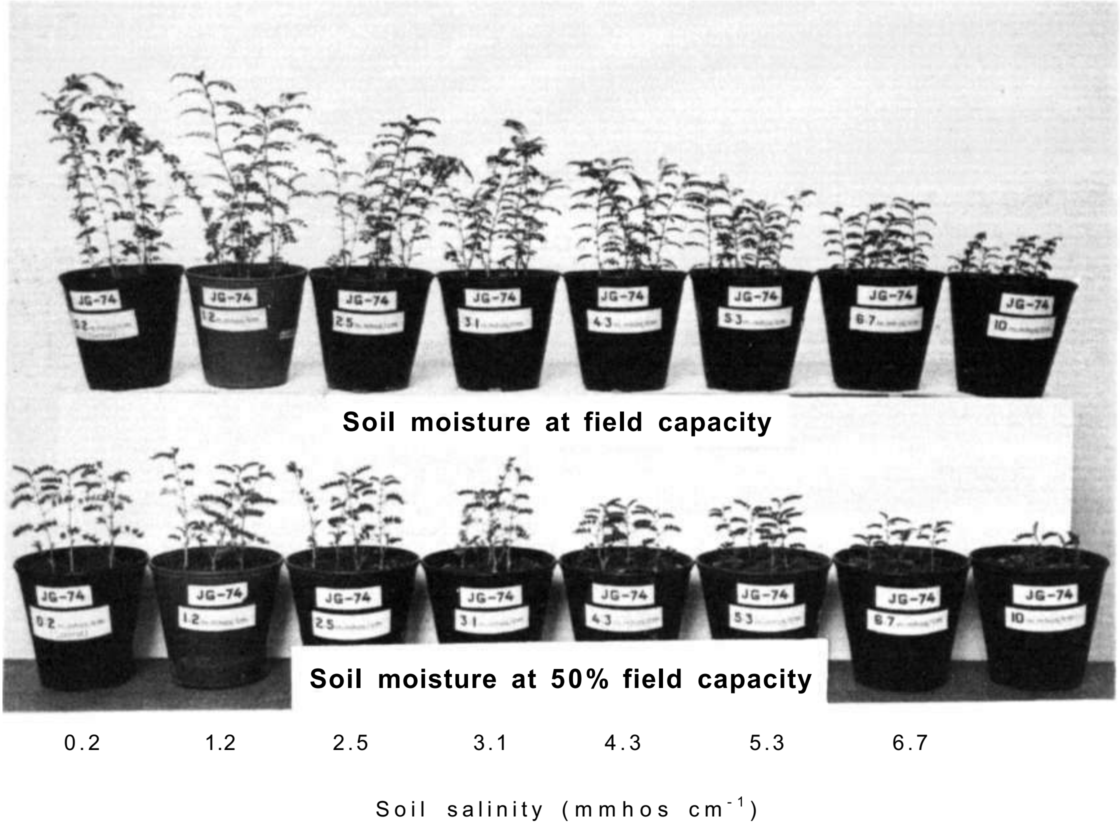

Figure 2. Effect of interaction between soil moisture and salinity on the growth of chickpea (cv JG 74).

salinity. Genotypic differences in tolerance to salinity appear to exist (Table 1), and a wide range of germplasm should be examined to determine the extent of such differences.

Interaction of Soil Salinity with Moisture

The osmotic effects of dissolved salts in soil solution, which contribute to physiological drought, are well recognized (Wyn Jones 1981). In the pot experiments conducted at ICRISAT Center to study the responses of chickpea to graded levels of salinity, we observed that the decline in dry matter in chickpea with increasing levels of soil salinity was more steep in well-watered conditions (pots maintained around field capacity) than in water-deficit conditions (pots maintained at around 50% of the field capacity) (Fig. 2). Studies in the field exhibited a similar response. This indicates that genotypic differences may be easier to detect when soil water conditions are kept at an optimum for plant growth.

Breeding for Tolerance to Salinity

Once considerable genotypic variability is detected by the screening methods discussed, a breeding program for salt tolerance becomes feasible. Genotypes with greater salt tolerance than the commonly grown cultivars can be selected as parents. The above screening techniques, however, would not be suitable for selecting promising material in a segregating population.

Generally, genotypic differences are greatly narrowed down at very high levels of salinity and, hence, such levels cannot be used to screen segregating populations in a breeding program. The attempt

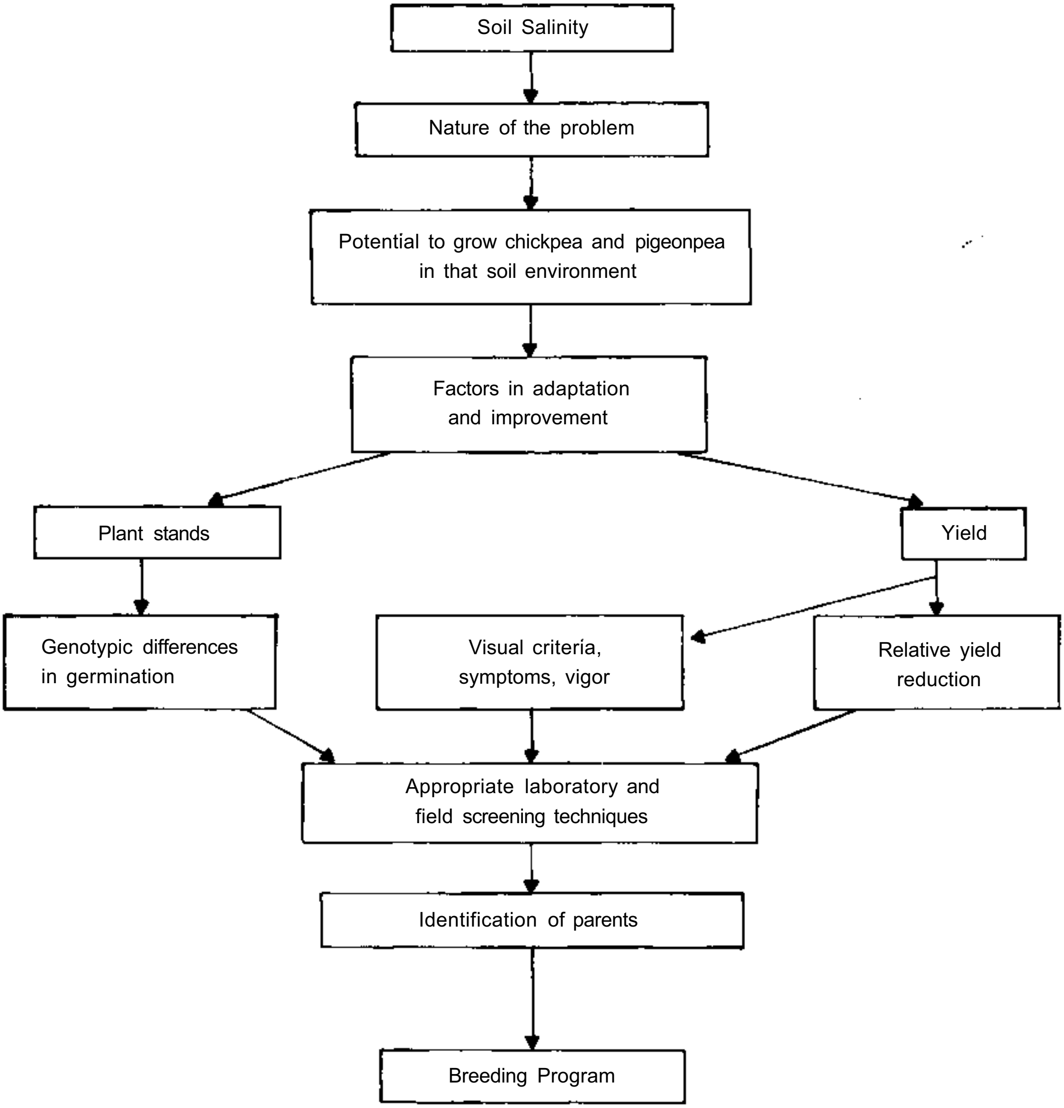

Figure 3. A schematic diagram of steps required for a breeding program on tolerance to soil salinity.

should be to arrive at an optimum level of soil salinity at which expression of genotypic variation is maximum. This level can be decided upon for a given soil type and climatic condition by growing a few contrasting genotypes at graded levels of soil salinity.

The chosen level of salinity can then be created in artificially salinized microplots in the field, or in pots, in which the segregating population can be grown. Selections and generation advancement can then be made on the basis of visual differences in relative growth and appearance of symptoms. The promising material could finally be tested more comprehensively at graded levels of soil salinity, in pots or in heterogeneous field conditions as described earlier.

An overall schematic approach is described in Figure 3. The approach may also be applicable to pigeonpea.

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Abiotic Stress and Nitrogen Fixation

Chairman: K.K. Lee
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Effects of Drought, Temperature, and Salinity on Symbiotic Nitrogen Fixation in Legumes, with Emphasis on Chickpea and Pigeonpea

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Abstract

*The legume-*Rhizobium *symbiosis is a highly integrated and, to a considerable degree, self-regulating process. It is particularly sensitive to such environmental influences as drought, salinity, and extremes of temperature, more so than rhizobia growing alone. Although the effect of these factors on the symbiosis has been studied mostly under laboratory conditions, a good understanding has been achieved of how the symbiosis responds to various forms of stress. All three stress factors impair the development of root hairs and the site of entry of rhizobia into the host, resulting in poor nodulation or even absence of nodules. Salinity and high temperature more greatly affect nodulated plants than nitrogen-fertilized plants. Since existing knowledge on the effects of stress factors on symbiotic nitrogen fixation has been derived mostly from studies with legumes other than chickpea or pigeonpea, detailed studies of these effects are needed for these two crops. In addition, because strains of rhizobia tolerant to these stress factors are either available or identifiable by laboratory screening procedures, efforts to identify individual chickpea and pigeonpea genotypes tolerant to these stress factors could help improve the overall tolerance of the symbiosis.*

Introduction

Nitrogen is both essential for plant growth and the element that most frequently limits crop production. Soil nitrogen is depleted by cropping, denitrification, leaching, and erosion; it is accreted by application of fertilizer nitrogen and manures, and by biological nitrogen fixation (BNF).

Knowledge of the BNF phenomenon is about a century old: BNF was recognized as a natural process that permitted legume growth on soils low in nitrogen. During the initial phase of knowledge acquisition, because sophisticated laboratory equipment was often lacking and fertilizer nitrogen not readily available, this subject did not attract much research effort. In the late 1950s and early 1960s, however, there was a strong surge of BNF research, particularly with regard to its biochemical aspects. Since the 1970s the field has expanded, as indicated by the frequency of international symposia and the increased number of books on BNF(Postgate 1971; Quispel 1974; Stewart 1975; Torrey and Clarkson 1975; Nutman 1976; Broughton et al. 1979; Bergerson 1980; Broughton 1981, 1982, 1983; Graham and Harris 1982), as well as reviews (Stewart 1973; Dazzo and Hubbell 1974; Dilworth 1974; Shanmugam and Valentine 1975; Child 1976; Skinner 1976; Winter and Burris 1976; Vance 1983).

Because the energy cost of synthesizing and transporting combined nitrogen as fertilizer is high and because increased use of fertilizer nitrogen may lead to pollution hazards, enhancing fixed nitrogen may

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become a viable proposition not only in marginal lands of the semi-arid tropics but also in good soils.

The profound influence of environment on symbiotic nitrogen fixation has been known for a long time. But little is known so far about the basic reaction underlying the variations in symbiotic nitrogen fixation in legumes, particularly chickpea and pigeonpea, as revealed under stress conditions. The results obtained so far with different legumes would seem to justify further research effort.

Since the estimates of nitrogen fixed by legumes in general are questioned (LaRue and Patterson 1981), we have refrained from estimating yield losses attributable to the effect of various stress factors on nitrogen fixation.

Drought

Few studies are available on the survival of rhizobia under drought stress. One study showed that, depending on species, between 50% and 99% of rhizobia died with cycles of wetting and drying (Pena-Cabriales and Alexander 1979). A 10000-fold reduction was also observed in the *Rhizobium* of *Lotus* when the soil was kept dry for several months (Foulds 1971). It was found that soil conditions under which drying occurs affect the extent of decline (Bushby and Marshall 1977), and that type and amount of clay in the soil are important for protecting rhizobia (Osa-Afiana and Alexander 1982). A population of 1000 rhizobia g^{-1} dry soil or more can be counted for both chickpea and pigeonpea in the surface 5-cm Vertisol soil during the hot, dry summers of peninsular India (Table 1). Thus, despite a decline in population over this period, rhizobia of both chickpea and pigeonpea (cowpea group rhizobia) can still survive drought. With appropriate selection pressures, it should be possible to identify rhizobia that are better able to survive drought conditions.

An optimum supply of water, around 60-75% of the water-holding capacity, is considered essential for maximum plant growth. Because symbiosis is an ultrasensitive process, however, its water requirements should be considered separately from those of the individual plants. Pigeonpea grown in the unpredictable rainy season, for instance, may experience either shortage or excess of water during vegetative growth. When reproductive growth extends into the postrainy season, the crop primarily depends on stored moisture in the soil. Chickpea and pigeonpea grown in the postrainy season thus face a progressively increasing soil moisture deficit. Legume symbiosis can recover if exposed to short stress periods, but prolonged exposure may lead to permanent damage and shedding of nodules (Wilson 1931, cited by Lie 1981).

Table 1. Effect of depth on population (log 10 MPN g^{-1} soil) of chickpea and cowpea group rhizobia in a Vertisol and an Alfisol, ICRISAT Center.

Depth (cm)	Chickpea rhizobia[1]		Depth (cm)	Cowpea group[2] rhizobia in Alfisol
	Vertisol	Alfisol		
0 5	4.62	4.81	0-5	3.38
5-15	5.34	4.61	5-10	4.65
15 30	3.85	3.89	20-30	4.19
30- 60	3.81	3.69	50-60	3.21
60-90	2.53	-[3]	100-110	3.37
90-120	2.13	-	150-160	3.30

1. Sampling done in May 1979 (ICRISAT 1980).
2. Sampling done in June 1978 (J.V.D.K. Kumar Rao and P.J. Dart, unpublished).
3. - = not determined.

Dry soils inhibit normal root hair formation and, hence, infection by *Rhizobium.* With watering, the abnormal root hairs may resume growth. On the other hand, nodule development initiated under normal moisture conditions is set back by later dry conditions (Worrall and Roughley 1976).

Sprent (1971) carried out detailed studies on the effect of drought on detached soybean nodules. When water loss from nodules exceeded 20% of the initial nodule fresh weight, acetylene reduction activity (ARA) was irreversibly lost. Splitting of cell walls and rupturing of plasmodesmatal connections occurred in the bacteroid-containing zone. Under these conditions, the cytoplasmic structure in the vacuolated cells of the nodule cortex collapsed (Sprent 1972a). Reduced respiration rates and ARA due to drought stress were seen when nodules were assayed at high pO_2 or after slicing or homogenization (Pankhurst and Sprent 1975). The results suggested that the cortical collapse inhibited nodule activity by reducing the diffusion of O_2 into the bacteroid-containing zone. Results of studies on detached nodules may not be applicable to nodules still attached to the host plant, but they do provide some interesting insight into the system.

Unless drought stress caused wilting of the lower leaves of *Glycine max* and *Vicia faba* , ARA recovered rapidly after watering (Sprent 1972b);

moreover, irrigation after a period of drying increased nitrogen fixation more than ten-fold (Sprent 1976). Reduced ARA during drought may be due to reduced photosynthate supply: in *Glycine max* , for instance, it was observed that the percentage reduction of ARA and of net photosynthesis were similar (Huang et al 1975a). The recovery of ARA after rewatering, however, lagged behind that of photosynthesis (Huang et al. 1975b). A 3-day drought stress imposed on *Glycine max* caused a 40-80% reduction in the proportion of ^{14}C-labeled photosynthates subsequently supplied to the nodules (Silivus et al. 1977).

Similar studies on chickpea and pigeonpea are lacking. A substantial increase in nodulation and ARA is seen due to irrigation in chickpea (Fig. 1). Without irrigation, the maximum nodule growth was achieved by about 40 days. With irrigation at about 10-day intervals, nodules continued growing until about 65 days and ARA continued even up to 89 days. Similar responses to irrigation were seen in nodulation and ARA of pigeonpea grown in the postrainy season (Fig. 2).

A water budget drawn up for a pea plant and its nodules for a period of rapid vegetative growth of 9 days, between 21 and 30 days after sowing, in an environment of 18°C during the day and 12° C during the night, indicated a requirement of 10 ml water by the nodules during this period (Pate 1976). Of this, 9.7 ml was estimated to have been used for exporting 27.3 mg of fixed nitrogen to the plant, and 0.3 ml was consumed in nodule growth. Twenty percent of the 10 ml came from the phloem, 13% was absorbed from the nodule surface, and the remaining 67% was extracted laterally from the adjacent roots. During the same period, 140 ml water was transpired by the plant, which was 14 times more than the amount passing through the nodules (Pate 1976). Although this estimate may not be precise, it clearly indicates that under normal conditions roots supply a major portion of the water required by nodules.

In chickpea growing in the postrainy season on receding residual moisture, the top 15 cm of the soil dries up within 3 weeks (N.P. Saxena, ICRISAT, personal communication), but nodules remain tur-

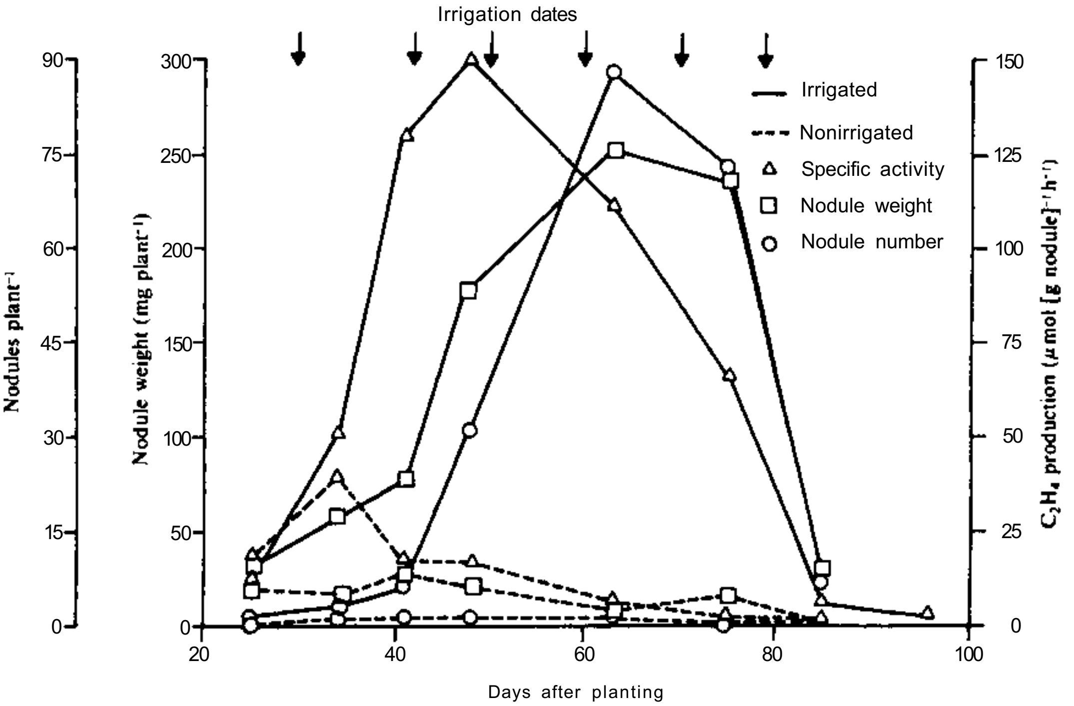

Figure 1. Nodulation and nitrogen fixation of cultivar K 850, with and without irrigation, in a Vertisol at ICRISAT Center, 1979/80 (ICRISAT Annual Report 1981, p. 93).

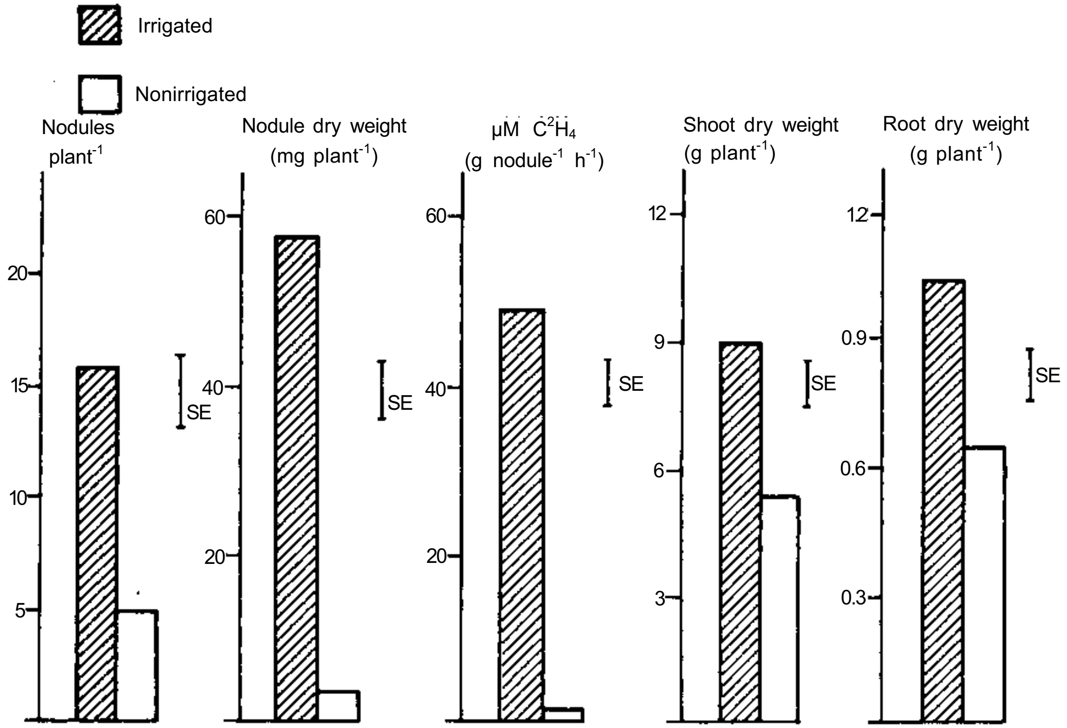

Figure 2. Effect of irrigation on nodulation, nitrogenase activity, and dry-matter production (at 90 days) of pigeonpea cultivar C 11 grown on a Vertisol, ICRISAT Center, postrainy season 1981/82. (Source: J.V.D.K. Kumar Rao and J.A. Thompson, unpublished).

gid and functional for more than 40 days after sowing (see Fig. 1). The water required for nodule functions is obviously coming from deeper layers. However, nodules may also be losing some water to the dry soil, instead of absorbing it. Since pigeonpea experiences unpredictable cycles of wetting and drying (Huda and Virmani 1987), dips and surges in nodule formation and functions during the growing season have been observed.

Chickpea in farmers' fields and in watersheds is generally not as well nodulated as in precision fields at ICRISAT Center, even though *Rhizobium* populations are similar. This indicates that lack of appropriate *Rhizobium* is not completely responsible for poor nodulation. The poor nodulation of legumes sown on residual moisture, compared to crops sown with irrigation, tempts us to say that the early processes of nodulation—such as infection by rhizobia, nodule initiation and formation, etc.—are rather more affected by moisture level than is nodule function. Rhizobia are known to survive various degrees of dessication expected in the soil, but we should concentrate on identifying plant genotypes that can form functional symbioses under drought conditions.

Temperature

The effect of temperature on nitrogen fixation was reviewed by Lie (1974, 1981) and Dart et al. (1976). Temperature can affect viability of rhizobia applied to seeds at sowing, growth and survival of saprophytic rhizobia in the soil, and the various symbiotic processes from recognition of rhizobia by legume roots to nodule function.

Rhizobia are susceptible to higher temperatures, particularly when conditions are moist rather than dry (Wilkins 1967). Survival of rhizobia on seeds of *Trifolium* spp, *Pisum sativum,* and *Medicago sativa* sown in moist soils was greatly reduced at 40°C. The degree of reduction depended on the size of the initial population, the time of exposure, and the strain of *Rhizohium* (Bowen and Kennedy 1959, cited in Bushby 1982). Although strains differ in their capacity to tolerate temperature, the upper limit is close to 40°C (Bowen and Kennedy 1959 and Ishizawa 1953, cited in Bushby 1982). Soil temperatures reaching 40°C are not uncommon in chickpea and pigeonpea growing areas (ICRISAT 1978), but the tolerance limits of these rhizobia are not yet known. However, the rhizobia of chickpea and pigeonpea do seem to survive these temperature conditions (see Table 1).

The temperature of the rooting medium has a strong influence on root hair infection (Frings 1976, cited in Sutton 1983) and ARA (Waughman 1977). In *Trifolium* nodules, it was observed that at 11-19°C the first senescent zones were detected 10 days after bacteroid differentiation, while at 7°C there was still no appearance of the senescent zone after 20 days (Roughley 1970). The longer period and higher nitrogen fixation rates for chickpea grown in northern India (29° 10'N) than in southern India (17°32'N) (ICRISAT 1982) may partly be due to lower temperatures, which can sometimes be <10°C.

It was noted that ARA of *Trifolium subterraneum* continued to increase for 3 days after transfer from 22° to 30°C, and then decreased by 90% in the next 3 days (Pankhurst and Gibson 1973). This was accompanied by marked structural changes in the bacteroid-containing cells and by accelerated growth and branching of infection threads. In contrast, nodules formed by a particular strain, TA 1, were fully stable at 30°C. In similar experiments with *Trifolium subterraneum, Trifolium pratense,* and *Medicago sativa,* reduced frequency was recorded of infection threads, as well as reduced ARA, on transfering plants from lower to higher root temperatures (Day and Dart 1970, cited in Dart 1977). Those observed differences in the reaction of infection threads could be due to different *Rhizo-ium* strains. *Pisum sativum* nodules formed at 22°C lost 67% of their ARA and 17% of their leghaemoglobin after 2 days exposure to 30°C (Frings 1976, cited by Sutton 1983). Both plants and rhizobia grew satisfactorily at 30°C when supplied with combined nitrogen.

With chickpeas, it was found that daily cycles of 23-33-23°C or 23-36-23°C root temperature during the day resulted in decreased ARA and plant growth (Dart et al. 1975). Two cycles did not affect plant growth significantly, but five and ten cycles caused an 18-34% reduction in nitrogen fixation over the control when measured 14 days after the treatment. When chickpea was grown continuously at four different temperature regimes with mean soil temperatures of 24°, 26°, 28° and 30°C during the day, nodule mass, ARA, and plant growth were adversely affected with increasing temperature (Table 2). ARA decreased 51% at 26°C, 79% at 28°C and 90% at 30° C, over the ARA obtained at 24° C, while the corresponding decrease in plant growth was 23, 52, and 67%. More ARA of chickpea nodules was observed when day-night temperature was 22-10° C or 22-18°C than when it was 30-10°C or 30-I8°C (Minchin et al. 1980).

At higher temperatures, photosynthesis is reduced drastically (Black 1973; Black et al. 1978) and hence nitrogen fixation can be indirectly affected by reduced supply of photosynthates. *Rhizohium* strains that can fix nitrogen under temperature stress conditions can be obtained (Ek-Jander and Fahraeus 1971; Lie 1974). For chickpea it has been possible to identify strains which can fix nitrogen at about 30° C, a temperature that the crop is expected to face in the conditions of peninsular India (ICRISAT 1978; ICRISAT 1984).

Table 2. Effect of soil temperature[1] (° C) on nodulation, nitrogen fixation, and plant growth of chickpea (ICRISAT 1983).

Temperature (°C)	ARA[2] (μM C_2H_4 pot^{-1} h^{-1})	Nodules pot^{-1}	Nodule dry mass (g pot^{-1})	Top dry wt (g por^{-1})
25	22.7	1480	1.95	21.9
30	11.1	1580	1.55	16.9
32	4.7	1490	1.33	10.4
35	2.2	800	0.83	6.8
SE	±1.79	±152	±0.163	±0.74

1. Plastic pots containing a Vertisol with a high *Rhizobium* count were immersed in water baths of different temperatures for 8 h per day (0800 to 1600), beginning 6 days after sowing
2. ARA = acetylene reduction activity.

Salinity

Information on the effect of salinity and alkalinity on rhizobia is scanty, and it is particularly lacking for chickpea and pigeonpea. Most of the available studies have used broth cultures, and the initial broth pH can change over the growth period (Damirgi et al. 1967). Growth of a range of strains in broths of initial pH 8.0 to 10.0 has been reported (Graham and Parker 1964). Only one slow-growing strain could grow at pH 9.0, but all strains of *Rhizobium meliloti* (fast growers) grew at pH 9.5. None of the strains could grow at pH 10.0.

Salts of Na and Ca are known to be toxic to *Rhizobium* at high concentrations. Salt (generally NaCl) concentrations of more than 1% inhibit the growth of rhizobia. It was observed that growth rates of rhizobia of chickpea and cowpea were reduced at more than 1% of NaCl (Gandhi and Vyas 1969). *Rhizobium trifoli* and *Rhizobium leguminosarum* were found to be sensitive to 0.4% $NaHCO_3$ (Wilson 1931, cited by Bushby 1982). Also KCl was more inhibitory than NaCl at equivalent concentrations (45 mM) for four strains of *Rhizobium japonicum* (Upchurch and Elkan 1977). Non-gum-producing colony variants from these four strains were more sensitive to salt than large, gum-producing colonies.

It was suggested that salts affect the host rather than the *Rhizobium* (Wilson 1970). However, the processes involving the interaction between the two are likely to be more sensitive to salinity and alkalinity. Roots of *Medicago sativa* growing with 0.2% $NaHCO_3$, for instance, were devoid of root hairs and mucilaginous layers and the formation of infection threads was prevented (Lakshmi Kumari et al. 1974). However, under the same salt concentrations, the growth of rhizobia was optimum. In soybean, high salinity caused shrinkage of root hairs and, hence, failure of nodulation (Tu 1981). Sodium chloride at 120 mM concentration inhibited nodulation of soybean. Plants depending on symbiotic nitrogen were more affected by salts than those depending on mineral nitrogen. In contrast, both nitrate-fed and symbiotic plants of *Medicago sativa* were relatively unaffected by salt (Bernstein and Ogata 1966). Nodulated mungbean was more affected by salinity than cowpea (Balasubramanian and Sinha 1976), and in *Vicia faba,* the reduced number of nodules per plant due to salinity was compensated in part by increased nodule size (Yousef and Sprent 1983).

Symbiotic susceptibility to salt stress also varies from salt to salt. In lucerne 0.7% NaCl completely suppressed nodule formation. However, nodules were formed even with up to 0.75% of KCl and $MgCl_2$ (Singh et al. 1972).

Growth of chickpea in sand culture in the greenhouse was depressed by NaCl at only 20 mM, unless mineral nitrogen was provided. Without NaCl, the performance of 22 *Rhizobium* strains was comparable to strains with an ammonium nitrate treatment; with addition of 75 mM NaCl, however, only one strain was significantly better than the control (Lauter et al. 1981). *Rhizobium* strains could grow with even up to 120 mM of NaCl, indicating that the symbiotic processes from root hair infection onward are more sensitive than from rhizobia alone.

Almost all the studies on nodulation and nitrogen fixation have been done with defined salts under laboratory conditions. Field situations would be different and more difficult to study. The laboratory studies provide a basic understanding of the system, and thus need to be done. Besides differences between legume species in tolerance to salt stress, there can be genotypic variability within a species. Five lentil cultivars tested at different salt concentrations indicated genotypic differences (Rai 1983). Differences between genotypes of pigeonpea do exist, but there is a need to identify genotypes tolerant to salinity levels experienced in the field (Y.S. Chauhan, ICRISAT, personal communication). A recently concluded study at ICRISAT Center indicated genotypic differences between pigeonpea lines and their associated rhizobia for tolerance to different salt concentrations (Subba Rao 1984).

Rhizobium strains obtained from salt-affected soils may be more tolerant to salinity and better able to establish a symbiosis with the host. Chickpea strain IC-53 (ex 161a), isolated from a saline field at ICRISAT Center, produced greater shoot weight than *Rhizobium* strains from normal fields, when compared in pots containing saline soil. This strain produced 63% more grain yield than the control treatment in field trials in a saline soil in Sudan (Ibrahim and Salih 1980). Similar observations were made for *Rhizobium* of *Sesbania* isolated from salt-affected soils (Bhardwaj 1972).

Conclusion and Future Research Needs

Most of our knowledge on the effects of stress factors on BNF comes from studies on legumes other than chickpea and pigeonpea. Hence, more studies on how these two crop plants react to the stress factors are required. *Rhizobium* strains growing as saprophytes in the soil can tolerate stress environments much better than the host legumes and the symbiosis. Also, *Rhizobium* strains tolerant to some of these stress factors have been isolated; they can also be identified more easily than tolerant host plants. Plants depending on symbiotic nitrogen are more prone to the adverse effects of drought, soil temperature, high pH, and salts than are plants fertilized with nitrogen. This suggests that identification of genotypes tolerant to these stress factors should be a first step in overcoming the adverse environmental effects. All the stress factors result in absence or distortion of root hairs, the site where rhizobia enter the host prior to establishment of the symbiosis. Hence, in selecting legume genotypes better able to tolerate stress factors, the ability to form normal root hairs should be a major consideration.

A study as to why, and at which stage, the symbiosis breaks down under environmental stress is important from a practical point of view, and it may provide more information about the process itself. An important contribution may be expected from a comparative study between genotypes that differ in their capacity to establish a symbiosis under stress conditions.

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Regional Problems

Chairman : R.P. Singh
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Effects of Climatic Stress and Soil Chemical Toxicities on Productivity of Chickpea in West Asia and North Africa

M.C. Saxena[1]

Abstract

A major part of West Asia and North Africa is characterized by a Mediterranean climate with cool or cold, wet winters and warm summers. Chickpea is an important food legume in this region, accounting for about 15% of the world chickpea crop. Most of the chickpea grown in the region is of the kabuli type. The soils used for chickpea production are generally calcareous and have a high pH. The major climatic stresses to which the crop is subjected include excessively high temperatures and drought during reproductive growth. Sowing in winter rather than in the traditional spring reduces the severity of these stresses and increases yields. Because in this strategy the crop's vulnerability to cold stress increases, varietal selections are being made for tolerance to cold. In addition, because high calcareousness of the soil results in induced iron deficiency in susceptible genotypes, negative selection is applied to eliminate this susceptibility.

Climatic Conditions

A major part of West Asia and North Africa is characterized by a Mediterranean climate, with large variations due to proximity to the sea as well as latitude and altitude (Table 1). For developing research strategies at the International Center for Agricultural Research in the Dry Areas (ICARDA), we recognize two major agroclimatic zones in the winter rainfall areas: a "lowland" zone (<1200 m altitude) and a "plateau" zone (altitude >1200 m). A transition area between these zones may, however, need separate consideration.

Areas considered suitable for growing chickpea are those with a mean daily temperature of 5-20°C during the growing season. Such areas are large in the cool subtropics receiving winter rainfall but small in cool temperate regions, while estimates are not available for cool tropics and cool subtropics with summer rainfall (Kassam 1981). Most of the area with thermal and moisture regimes adequate to permit a reasonable length of growing period falls within the areas having Mediterranean climates. In these regions, crop production essentially depends on the amount of winter precipitation, which largely determines the length of the growing season.

In these regions, chickpea is primarily grown in areas where winter precipitation is more than 400 mm. In areas of less precipitation but with a thermal regime permitting an adequately long growing period for economic yields, the crop is grown with irrigation (supplementary or total). The Nile Valley of Egypt and Sudan is a good example. In areas receiving adequate winter rain, however, the crop is sown at the end of the main rainy period.

Chickpea is traditionally sown in most of West Asia and North Africa as a spring season crop, during March-April, after the end of the major rainy period, and the crop grows on the residual soil moisture. The crop experiences increasing temperatures and daylength. The long-term average values for maximum, minimum, and mean air temperatures and soil temperatures for two locations in West Asia are given in Figure 1. The evaporative demand of the atmosphere also increases during this period; the crop completes its reproductive growth and reaches maturity in an increasingly desiccating environment and under increasing soil moisture deficits.

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Table 1. Major variations of the Mediterranean climates in the thermal subtropics (After Kassam 1981).[1]

	Warm Mediterranean <1500 mm		Cool Mediterranean >1500 mm	
Regime	Oceanic	Continental	Oceanic	Continental
Thermal	Cool or cold winter with warm or hot summer	Cool or cold winter with warm or hot summer	Cold winter with cool summer	Cold winter with cool summer
	Annual fluctuations <25°C	Annual fluctuations >25°C	Annual fluctuations <25°C	Annual fluctuations >25°C
Moisture	Humid to desert	Semi-arid to desert	Subhumid to desert	Semi-arid to desert

1. Temperature (°C): cold = <5; cool = 5-18; warm = 18-30; and hot = >30. Rainfall (mm): humid = 1000-2000; subhumid = 600 -1000; semi-arid = 200-600; arid = 100-200, and desert = <100.

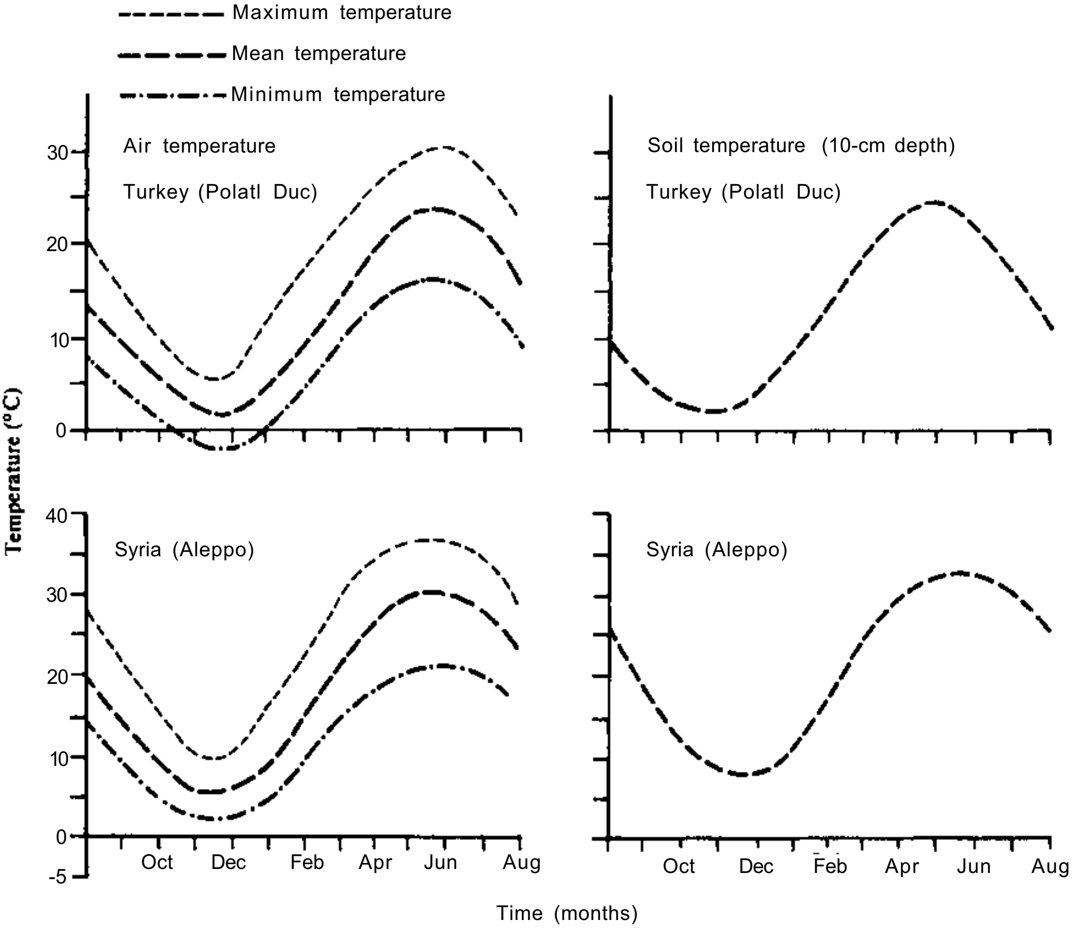

Figure 1. Seasonal pattern of air and soil temperatures at two locations in West Asia.

Soil Types

A detailed description of the major soil types in West Asia and North Africa was given by Kassam (1981). The areas where climatic conditions permit a crop-growing season of 75-210 days, conducive to chickpea crop production, are dominated by Cambisols, Xerosols, Lithosols, and Luvisols in North Africa and by Xerosols, Lithosols, Cambisols, and Regosols in West Asia (Table 2). Chickpea is also grown on Vertisols in this region. Calcium carbonate content and pH are high, and this influences crop productivity.

In Sudan, soil salinity and alkalinity have been serious limitations to crop growth, particularly after agricultural expansion in the areas with "high-terrace" soils in northern Sudan (Ayoub 1974,1975). Salinization has occurred over thousands of years by transportation of salts in the flood and delta plain of the twin rivers, Tigris and Euphrates, affecting crop production in Iraq(Delver 1962). Due to the hot and arid climate and limited natural drainage, the salts brought in the flood and irrigation water have accumulated in the groundwater, which usually contains 3-5% salt. Depending on topography, this affects crop production.

Table 2. Major soil groups in areas of North Africa and West Asia where chickpeas are grown or which have potentially suitable growing seasons (After Kassam 1981).

	Rank in subregion	
Soil group	North Africa	West Asia
Cambisols	I	3
Lithosols	3	2
Fluvisols	7	9
Luvisols	4	5
Regosols	6	4
Vertisols	9	7
Xerosols	2	1
Yermosols	5	6
Solonchaks	8	8

Area, Production, and Yield of Chickpea

The area, production, and productivity of chickpea in the world and in the ICARDA region are shown in Table 3. Almost all of the chickpea crop in Alge-

Table 3. Average area, production, and yield of chickpea in major producing countries of the ICARDA region, 1966-70 and 1976-80 (FAO 1980).

	1966-70			1976-80		
Country	Area ('000 ha)	Production ('000 t)	Yield (kg ha^{-1})	Area ('000 ha)	Production ('000 t)	Yield (kg ha^{-1})
Algeria	30	15	480	39	21	560
Egypt	4	6	190	5	9	1690
Libya	-[1]	-	-	-	-	1180
Morocco	116	77	680	67	42	610
Sudan	2	2	880	-	3	930
Tunisia	25	10	390	38	23	570
Cyprus	-	-	-	1	1	620
Iran	98	49	500	37	41	1120
Iraq	5	4	710	14	9	580
Jordan	3	2	540	2	1	360
Lebanon	3	2	710	I	2	1840
Pakistan	1073	572	540	1123	550	490
Syria	42	336	810	57	35	660
Turkey	88	102	1160	174	211	1200
Totals						
ICARDA region	1489	877	590	1558	948	610
World	10247	6210	610	10263	6745	660

1. indicates data not available.

Table 4. Timing of low and high temperature extremes, with a frequency of 1 year in 13, at four locations in northern Syria (After Harris 1979).

Location	(N)	Altitude (m)	Date of last frost (min T < 0°C)	Date of first max T > 33° C	Date of first max T >36°C
Hama	35°08'	309	3rd wk March	3rd wk April	2nd wk May
Aleppo	36° 11'	392	1st wk April	3rd wk April	3rd wk May
Tel Abiad	36°42'	355	2nd wk April	2nd wk April	3rd wk May
Kamishly	37°03'	452	1st wk April	4th wk April	2nd wk May

ria, Cyprus, Egypt, Iraq, Jordan, Lebanon, Libya, Morocco, Syria, Tunisia, and Turkey is of the kabuli type, whereas about 30% of the crop in Iran and 5% in Pakistan is of this type (Singh et al. 1983). In Sudan a small proportion of the total area is cropped with the desi type. The ICARDA region contributes about 14-15% of the total area and production of chickpea in the world. Chickpea is the most important food legume crop in West Asia, whereas in North Africa it is second only to faba beans (*Vicia faba*). There has been a slight increase in area, production, and productivity of chickpea in the region from 1966-70 to 1976-80.

Most of the chickpea in the region is grown under rainfed conditions, except in Egypt and Sudan, where it is irrigated. Except in Egypt, Sudan, and Pakistan, the crop in this region is sown at the end of winter or in early-to-late spring, depending on the altitude and general thermal regime of the area.

Major Climatic and Soil Stresses

The major environmental stresses that limit chickpea productivity in the region include:

a. drought in the growing season, particularly at the flowering and pod-filling stages;
b. cold at early stages of crop growth;
c. high calcareousness of the soil and high pH; and
d. salinity and alkalinity problems in some areas.

Of the factors listed above, the climatic stresses are more limiting than the soil stresses, in terms of both severity and distribution of effect. The timing of low and high temperature extremes, with a frequency of 1 year in 13, at four locations in Syria is shown in Table 4. It is evident that frost could occur as late as in the second week of April in the lowlands of West Africa, and temperatures may rise to more than 33°C by the same time and to more than 36°C by mid-May. Thus the chickpea crop is vulnerable to both high and low extremes of temperature. The rapid rise in temperature in April is accompanied by increasing soil moisture depletion, exposing the crop to a combination of high temperature stress and drought stress.

Strategy to Tackle the Problems

High Temperature and Soil Moisture Deficits

No program has been initiated at ICARDA to develop specific heat- and drought-tolerant genotypes. However, a production technology has been developed which attempts to match chickpea crop phenology with the availability of optimum temperature and moisture regimes (Saxena 1984). Winter sowing of chickpea using ascochyta blight resistant cultivars, permits better matching of the reproductive phase of the crop with optimum temperature and moisture regimes than is possible with the spring-sown crop (Figs. 2 and 3). The success of this strategy is reflected in a near doubling of seed yield over the traditional spring sowing, and in the possibility of growing rainfed chickpea in areas of West Asia and North Africa where rainfall is <400 mm.

The advancement of sowing from spring to winter, however, poses some hazards that must be taken into consideration. One such is increased vulnerability of the crop to cold.

Cold Stress

Attempts are being made to incorporate a greater degree of cold tolerance in the material being developed for winter sowing. In addition to screening chickpea germplasm at Hymana on the Anatolian plateau, field screening of chickpea material has

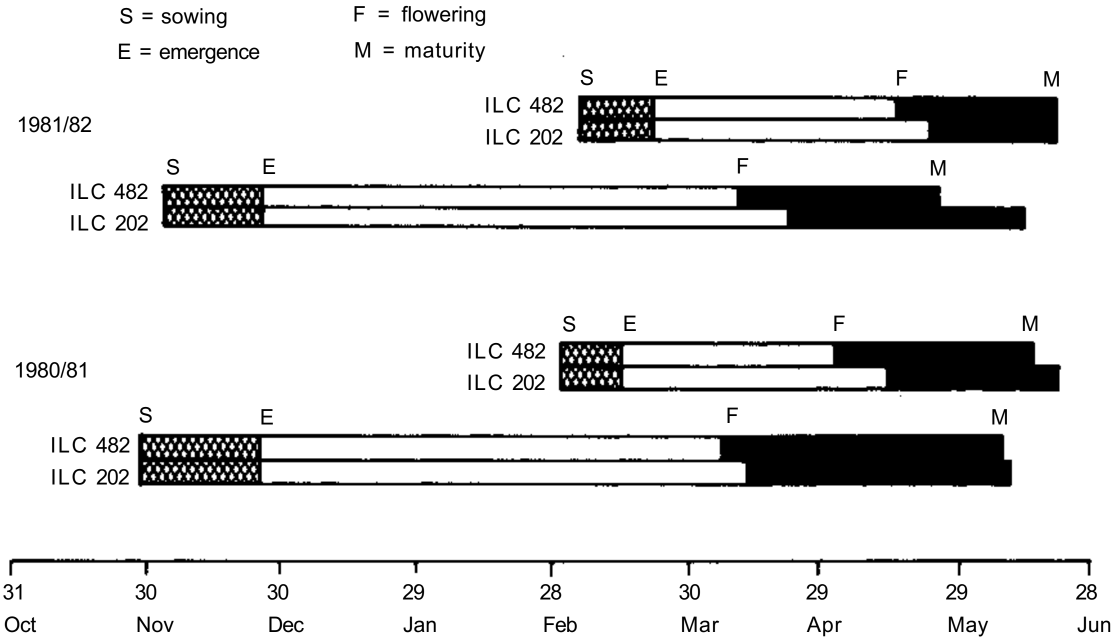

Figure 2. Effect of sowing date on the phenology of chickpea genotypes ILC 482 and ILC 202 at Tel Hadya, Syria, 1980/81 and 1981/82.

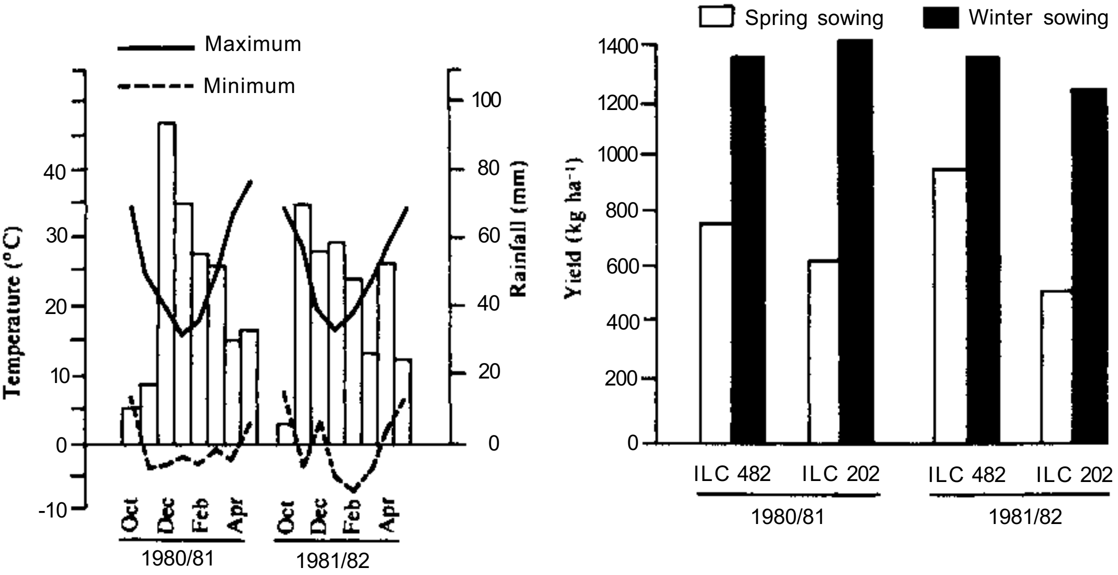

Figure 3. Monthly total rainfall and maximum and minimum temperatures in 1980/81 and 1981/82 at Tel Hadya, Syria, and the effect of winter and spring sowing on seed yield of chickpea genotypes ILC 482 and ILC 202 in those seasons.

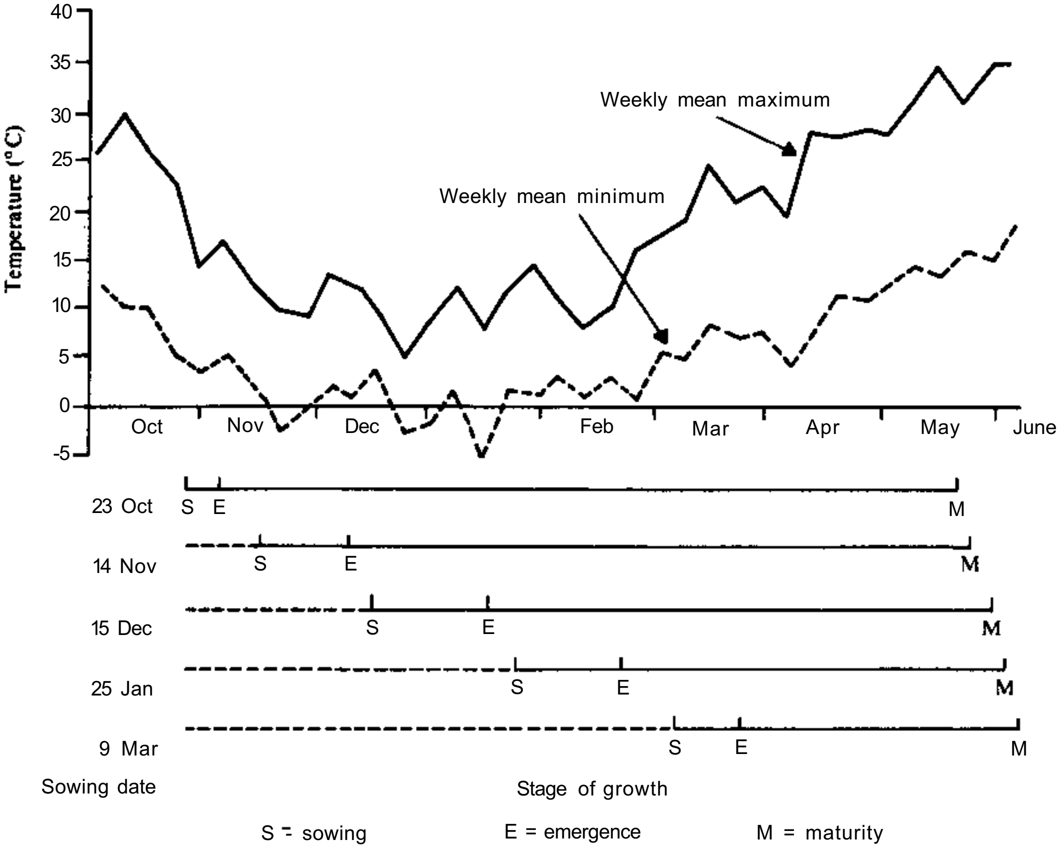

Figure 4. Exposure of chickpea genotypes, sown on different dates, to different temperatures at Tel Hadya, Syria, during the 1982/83 season.

been done at Terbol, in the Beka'a valley of Lebanon, and at Tel Hadya in Syria.

At Tel Hadya, advancement of sowing date has been attempted to increase the probability of good cold tolerance screening (Fig. 4) as frost occurrence is much higher at earlier dates (Harris 1979). At Tel Hadya, during the 1981/82 season, there were 43 nights with temperatures below freezing point, causing severe damage to the chickpea genotypes tested and thus permitting an excellent opportunity to screen for cold tolerance. Genotypes that could withstand cold were identified at a time when standard local controls were completely killed. The accessions selected include ILC numbers 666, 668, 1071, 2487, 2505, 3081, 3287, 3470,3598, and 3789. These are now being used in the breeding program. The cold tolerance of these genotypes is further verified by exposing them to -6°C in freezing chambers for various lengths of time.

Soil Calcareousness and Other Soil Problems

Many soils in the chickpea-growing areas of West Asia and North Africa are calcareous, with the calcium carbonate content being more than 20%. Salinity and alkalinity are also fairly widespread in the region. Because chickpea is not normally grown in such areas, however, the problems of salinity and alkalinity assume significance only when expansion of chickpea-growing areas is considered. Iran, Iraq, and Sudan have problems of salinity and alkalinity in some of their chickpea-growing areas (Delver

1962; Ayoub 1974, 1975; Ageeb and Ayoub 1977). Studies at Hudeiba Research Station in northern Sudan have shown that the host- *Rhizobium* symbiosis may be impaired by salinity; this can be rectified by introducing chickpea *Rhizobium* strains tolerant to salinity (Ibrahim and Salih 1980).

No work is being carried out at ICARDA on salinity tolerance. However, the susceptibility of chickpea to iron chlorosis, which occurs in calcareous soils, is being tackled by effecting negative selection. The susceptible types are rogued out at an early stage in the breeding scheme followed at ICARDA. Genotypes differing in susceptibility to iron deficiency have been identified, and the physiological basis of this difference is being studied in cooperative research with the University of Hohenheim, West Germany. Solution culture studies have shown that some of the tested susceptible types require higher concentrations of iron in the solution than the tolerant types.

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Potential of Chickpea and Constraints to its Production in Pakistan

Zaibunnisa Abdullah[1]

Abstract

Chickpea is an important postrainy (winter)-season crop in Pakistan, which has the second highest area and production of chickpea in the world. Average yields are low, around 440 kg ha^{-1}, but potential yields are quite high, above 2000 kg ha^{-1} The abiotic stress factors of drought, salinity, and sodicity seem to be important yield reducers. Although research on chickpea has not been extensive in Pakistan, several lines of research on agronomy and physiology have recently been suggested. Such research should enable proper identification of the constraints to production, and solutions to these problems should lead to increased and more stable production of chickpea in Pakistan.

Area and Production

Chickpea is an important postrainy (winter)-season pulse crop in Pakistan, grown in most regions of the country. Pakistan is also the second largest chickpea-growing country in the world (Malik 1984), after India.

Of a total geographic area of 80.5 million ha in Pakistan, 40.5 million ha are nonarable lands, mountains, and deserts. The area under chickpea fluctuates between 0.8 and 1.2 million ha (Table 1). The most important chickpea-growing region in Pakistan is the central region (30-40° N and 70-76° E). This includes areas in Punjab, such as Sargodha, Dera Gazi Khan, and Rawalpindi. Punjab accounts for 76% of the total area under the crop, and 74% of the national production (Table 2).

Second in importance is the southern region (located within 24-28° N and 68-72°E), represented by Sind, Sukkur, and Jacobabad. Sind accounts for 13% of the area under the crop and around 21% of the total production.

In the northern region (32-36°N and 68-72°E), which includes the North West Frontier Province (NWFP) and Dera Ismail Khan, the area under the

Table 1. Area, production, and productivity of chickpea in Pakistan, 1978-1983 (FAO Area and Production Yearbooks).

Year	Area (XXX) ha)	Production (XXX) t)	Yield (kg ha^{-1})
1978	1099	614	558
1979	1224	538	439
1980	1129	313	278
1981	961	387	403
1982	850	275	324
1983	893	491	550

Table 2. Area, production, and yield of chickpea in Pakistan, 1978-79 (Crops Statistics of Pakistan 1979).

Location	Area (XXX) ha)	Production (XXX) t)	Yield (kg ha^{-1})
Punjab	934	399	427
Sind	164	115	699
North West Frontier Province	125	23	188
Baluchistan	1	1	727
Pakistan	1224	538	439

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ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Adaptation of chickpea and pigeonpea to abiotic stresses. Proceedings of the Consultants' Workshop, 19-21 December 1984, ICRISAT Center, India. Patancheru A.P. 502324, India: ICRISAT.

crop is only marginally smaller than in the southern region, but average yields are very low.

Chickpea yields are generally low in Pakistan and average yields fluctuate annually (Table 1). However, yields as high as 2000-2500 kg ha^{-1} have been harvested in experiments (PARC 1984), indicating the potential for improving this crop in the country. The large yield gap between the potential and realized yields results from the incidence of both diseases (primarily ascochyta blight) and pests (pod borer, cutworm, and seed weevils), as well as the unfavorable soil conditions under which crop is grown.

Climate

It is possible to divide Pakistan into three distinct agroecological zones for chickpea cultivation (Malik and Tufail 1984). They are:

1. The northern region. This includes the North

Table 3. Some climatic parameters[1] in the northern region[2] of Pakistan (Pearce and Smith 1984).

	Temperature (°C)				Relative humidity (%)		Precipitation	
	Average daily		Highest recorded	Lowest recorded	0800 hours	1600 hours	Average monthly (mm)	Average no. of days with >2.5 mm
Month	Max.	Min.						
Jan	17	4	24	-3	73	45	36	3
Feb	19	6	30	-1	75	43	38	3
Mar	24	11	34	2	68	43	61	5
Apr	29	16	42	5	59	39	46	4
May	37	21	48	11	41	28	20	2
Jun	41	25	49	18	43	25	8	1
Jul	39	26	50	21	61	38	33	2
Aug	37	26	48	20	70	45	51	3
Sep	36	22	43	14	65	39	20	2
Oct	31	14	38	11	60	32	5	1
Nov	25	8	33	1	63	40	8	I
Dec	19	4	28	-2	73	42	18	2

1. Based on mean of 30 years' data.
2. Represented by Peshawar: 354 m; 34°01'N, 34° E.

Table 4. Some climatic parameters[1] in the central region[2] of Pakistan (Pearce and Smith 1984).

	Temperature (°C)				Relative humidity (%)	Precipitation		Potential evapotranspiration (mm day^{-1})[3]
	Average daily		Highest recorded	Lowest recorded		Average monthly (mm)	Average no. of days with >2.5 mm	
Month	Max.	Min.			1200			
Jan	16	2	24	-4	44	64	7	1.0
Feb	19	6	31	-2	46	64	6	2.1
Mar	24	10	36	1	37	81	7	3.0
Apr	31	15	44	7	26	42	6	5.2
May	37	21	46	12	19	23	4	7.2
Jun	40	25	48	14	23	55	7	8.1
Jul	36	25	46	17	45	233	13	5.4
Aug	34	24	42	14	54	258	10	4.5
Sep	34	21	39	12	44	85	5	4.1
Oct	32	15	38	7	29	21	2	3.2
Nov	28	9	32	-1	26	12	1	2.0
Dec	20	3	27	-3	39	23	3	1.1

1. Based on mean of 30 years' data.
2. Represented by Islamabad: 511 m; 33°35'N, 73°03'E.
3. Data calculated at Chaklala, Islamabad: 508 m; 33° 17'N, 73°06'E.

West Frontier Province and is characterized by high rainfall. Although they do not represent the entire region, data for one site in the region are given in Table 3.

2. The central region. This area is mostly semi-arid (Table 4). The region has been further subdivided by Malik and Tufail (1984) into central west and central east; the central west region receives relatively less rainfall during both the rainy and postrainy seasons. It includes Sargodha and Mianwali, and parts of Attock and Jhelum. The central east, including Rawalpindi and Sialkot, receives a higher rainfall.

3. The southern region. This zone is represented by Sind, Sukkur, and Hyderabad divisions. The area is at a relatively low altitude and the rainfall is scanty (Table 5).

Soils in Chickpea-Growing Regions

Soils in the North West Frontier Province and the central regions range from sandy to sandy loams. They are poor in organic matter and alkaline in reaction. The cation-exchange capacity ranges between 8 and 16 meq $(100\ g)^{-1}$ of soil. Ilike and chlorite are the predominant clay minerals, with small amounts of kaolinite.

In Sind and other areas in southern Pakistan, the soils have a relatively greater moisture-retention capacity. Chickpea is normally grown on fields vacated after the harvest of paddy in this region

Table 5. Some climatic parameters in the southern region of Pakistan (Pearce and Smith 1984).

	Temperature (°C)				Relative humidity (%)		Precipitation	
	Average daily		Highest recorded	Lowest recorded	0800 hours	1600 hours	Average monthly (mm)	Average no. of days with >2.5 mm
Month	Max.	Min.						
Jacobabad[1]								
Jan	23	7	28	0	65	34	5	0.7
Feb	25	9	37	-1	54	35	8	0.9
Mar	33	16	43	7	45	31	5	0.7
Apr	39	22	47	11	41	30	5	0.5
May	44	26	51	17	43	27	3	0.4
Jun	46	29	53	22	57	31	8	0.3
Jul	43	30	52	24	65	42	23	1
Aug	40	28	47	20	71	49	23	1
Sep	39	24	45	16	68	40	5	0.3
Oct	37	19	42	11	56	31	0	0.1
Nov	31	12	37	4	56	29	0	0.1
Dec	24	7	28	1	63	31	5	0.5
Karachi[2]								
Jan	25	13	32	4	63	45	13	1
Feb	26	14	34	6	72	49	10	1
Mar	29	19	41	8	79	57	8	1
Apr	32	23	44	14	87	62	3	0.2
May	34	26	48	18	88	68	3	0.1
Jun	34	28	46	20	86	69	18	1
Jul	33	27	43	23	88	73	81	2
Aug	31	26	37	23	90	74	41	2
Sep	31	25	41	21	89	71	13	1
Oct	33	22	42	14	83	57	0	0.1
Nov	31	18	38	9	68	49	3	0.3
Dec	27	14	33	4	64	45	5	1

1. 57m; 28° 17'N, 68°29'E; mean of 10 years' data.
2. 4m; 24°48'N, 66°59'E; mean of 43 years' data.

(Malik and Tufail 1984), and the soils generally have a good moisture status at the time of seeding.

Chickpea crops generally respond to the application of both nitrogen and phosphate fertilizers (Malik 1981).

Soil Moisture and Chickpea Production

The low national yields of chickpea are considered to be primarily because of its cultivation as a rainfed crop (Malik and Tufail 1984). The variation in monsoon precipitation in a year determines both the area planted to the crop and its productivity. The central region has the maximum area under chickpea, but yields are lower than in the southern region. Although the relative importance of various abiotic factors in reducing yields has not been estimated, soil moisture deficit seems to be a major constraint. This is because of the occurrence of sandy and loamy soils and inadequate rainfall in the central west region. Chickpea is also grown with surface irrigation in this region, but a large area remains rainfed.

There is an urgent need to more precisely quantify the effect of soil moisture on chickpea production in different chick pea-growing areas of the country, as suggested below.

1. Analysis of the climatological data that is available for the various important chickpea-growing tracts in the country, particularly in terms of rainfall and its distribution, temperature (maximum and minimum), and evaporative demand. Wherever such data are not available, appropriate recording facilities should be established immediately.
2. Mechanical and physicochemical characterization of soils on which chickpea is grown. Information on physical constraints, such as maximum water-holding capacity, field capacity, and permanent wilting point needs to be compiled for chickpea soils. Phosphorus fertility on experiment stations and farmers' fields needs to be evaluated.
3. Data of agronomic experiments on responses to irrigation in chickpea need to be compiled. This would give an indirect measure of the magnitude of losses in yield due to drought or soil moisture deficit.
4. In surveys conducted for estimating the incidence of diseases and pests, plant stands in farmers* fields need to be recorded. These data can be correlated with data for soil moisture at seeding time to estimate the losses in plant stands caused by suboptimal seedbed moisture.

Soil Salinity

Chickpea is grown on a wide variety of soils in Pakistan, but its cultivation is avoided on the saline and alkaline soils (Malik and Tufail 1984) because of the extreme sensitivity of the crop to those conditions.

The distribution of salt-affected soils in Pakistan as of 1973 is given in Table 6. According to more recent estimates (Mohammad 1978), 9.3 million ha of the irrigated area (representing about 44% of the cultivated area) in Pakistan are affected by salinity. In Punjab (Pakistan), 81% of the salt-affected soils are saline-sodic and the remaining 19% are saline. In Sind, 51% of the salt-affected soils are either saline-sodic or sodic, and 49% are saline. Since the areas which have become saline-sodic and saline in regions where chickpea can be cultivated are extensive,

Table 6. Area ("000 ha) under different categories of salt-affected soils (Mohammad 1973).

Location	Saline	Saline-sodic		Sodic	Total	Gypsiferous saline-sodic
		Permeable	Impermeable			
Punjab	505	1226	857	-	2588	57
Sind	1343	673	278	28	2322	339
North West Frontier Province	502	5	9	–	516	6
Baluchistan	175	125	4	-	304	90
Pakistan	2525	2029	1148	28	5730	492

improved chickpea production becomes dependent on identifying crop varieties with greater salt tolerance.

Reclamation of Saline Soils

Reclamation of saline and sodic soils has received considerable attention in this country. A good review of the situation was presented by Mohammad (1978). Recently a coordinated project on saline agriculture was started at the National Agricultural Research Center for the reclamation of saline-sodic soils in Pakistan. The major emphasis of this project is on removing salts from the rhizosphere through leaching the soils with HCI, followed by drainage (construction of horizontal and vertical drainage). Large areas have already been reclaimed using these methods, and further areas are being reclaimed, as at the experimental research station of the Pakistan Agricultural Research Council (PARC) at Sadhoki in Lahore.

The rising water table, which contributes to increasing soil salinity, is being checked through lining the canals and distributaries. Attempts are also being made to lower the levels of existing water tables by conducting poor-quality water out and recycling better quality water in through irrigation from tubewells. Such efforts have paid dividends and have been effective in lowering the water table in some areas of Punjab. This work is coordinated by the Water and Power Development Authority.

Work on improving saline-sodic soils through chemical amendments and irrigation management is concentrated at Karachi University. The recommendation to use sea water or underground brackish water with some nutrient amendments (Ahmad and Abdullah 1980, 1982a) has been found effective in ameliorating large areas in the coastal regions of Karachi and some inland areas of Sind.

The possibility that the process of reclamation can be hastened by the use of salt-tolerant grasses such as *Diplachne fusca,* which is used as fodder, has been investigated at Faisalabad. The process of reclamation would also be hastened by breeding cultivars of crop species more tolerant to salinity.

Management under Saline Conditions

Work on management practices to use brackish water for afforestation as well as agricultural purposes has been initiated on the sandy soils of the coastal regions. This work includes studies on using diluted sea water at safe levels for irrigation of agricultural crops. For example, in beetroot, chemically amended water, with salt levels up to 12000 ppm, could be used without any loss in the yield of root tubers (Ahmad and Abdullah 1982b). It was interesting to note that, in fact, cotton yields increased as salinity was increased to moderate levels.

Application of small amounts (5-10 ppm) of micronutrients, namely, Zn, Cu, Mn, and Fe, significantly increased wheat yields in saline (around 8.5 mmhos cm^{-1}) environments (Abdullah 1984). This indicates that saline conditions affect the uptake of nutrients.

Results of these studies on management to ameliorate salinity effects appear promising in crop plants and need to be investigated with respect to chickpea as well.

Plant Responses in Saline Environments

Much work has been done—on crops other than chickpea—on cellular adaptation under saline environments. The relative uptake of Na+, K+, Cl-, and Na+/K+ ratios, have been used to classify crops for tolerance to salinity. Crops such as taramira *(Eruca sativa),* wheat, maize, and sugarcane are considered sodium excluders, whereas cotton and sugarbeet are classified as sodium accumulators. In all studies, reproductive growth was more severely affected than vegetative growth (Ahmad and Abdullah 1979).

In potatoes grown on saline soils using gypsum as an amendment, accumulation of inorganic salts was found superior to accumulation of organic solutes in conferring salt tolerance (Abdullah and Ahmad 1982).

The high pH in saline-sodic soils has been found to induce nutrient imbalances, such as iron deficiency. Chickpea can be particularly sensitive to iron deficiency (Saxena and Sheldrake 1980), and yield reductions in chickpea due to iron deficiency need to be assessed in Pakistan.

Selection of Salt-Tolerant Cultivars of Crop Species

Studies on biochemical changes in response to soil salinity are in progress in crops such as safflower, wheat, maize, and cotton. Breeding for tolerance to soil salinity has already been initiated in crops such as sugarcane, rice, and wheat. Genotypic differences in yield for tolerance to different dilutions of sea water have been observed (Ahmad and Abdullah 1982b). This work should be extended to chickpea.

The Na+/K+ ratio, which has been used to discriminate between crops tolerant of and susceptible to salt, should be assessed for its use in detecting salt-tolerant chickpea genotypes.

Conclusion

Any of several abiotic factors may affect the productivity of chickpea in Pakistan and contribute to the low national yields. The abiotic constraints to production do not seem to be unique to Pakistan and are similar to those affecting the crop in India and West Asia. The relative severity of drought, salinity, and sodicity affecting chickpea production needs to be quantified and steps need to be taken to alleviate or overcome these constraints, so that increased and more stable yields can result.

Acknowledgement

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Soil and Climatic Environment in the Caribbean Region: Yield Reductions in Pigeonpea due to Drought, Salinity, Acidity, and Alkalinity[1]

R.P. Ariyanayagam[2] and S.M. Griffith[2]

Abstract

Grain legumes are important in the Caribbean region both as a food source and for their use in improving soil fertility. To increase the low yields of grain legumes, including pigeonpea, cultural practices, such as increasing cropping intensity and improving management practices, have been adopted. Legumes are grown on a number of soils including Vertisols, Alfisols. Mollisols, Entisols, Inceptisols, Ultisols, and Oxisols. Native soil fertility is generally poor, and both nitrogen and phosphorus limit the production of legumes. Unlike other legumes, traditional tall pigeonpeas do not respond to the application of fertilizers, but responses can be obtained from improved dwarf cultivars. The abiotic stresses of drought, heat, waterlogging, salinity, and sodicity reduce pigeonpea yields in the Caribbean region. Alleviation of all these stresses by improved management factors is impractical; therefore, genetic improvement of the crop for tolerance and avoidance of these stresses is recommended.

Introduction

The Caribbean region stretches from Belize on the Central American mainland, through the archipelago of the West Indian islands, from as far north as Bermuda and the Virgin Islands, to Guyana, French Guyana, and Surinam in South America. The diversity and differentiation of soils in this region has been well documented (Regional Research Centre 1958-1974; Applewhite 1965; Brinkman 1965, 1966; Land Capability Survey of Trinidad and Tobago 1965-1967; USDA 1972).

Soils in the Caribbean region owe their heterogeneity to differences in parent material in different areas and the variation in climatic factors, in particular the intensity and distribution of rainfall, which affects weathering processes. The suggestion that many unique soil types may occupy only a few hectares (Smith 1983) must be considered when mapping inclusions of the soil series with a similar response to factors of management.

This paper describes only the soils on which pigeonpea (*Cajanus cajan* [L.] Millsp.) is cultivated in the Caribbean region; the goal is to identify constraints to production and to suggest appropriate strategies to alleviate those limitations.

Description of the Soils

The major soil types on which legumes are cultivated are clays, clay loams, loams, sandy loams, and loamy sands. Agronomically, the clays and clay loams are the most important soils in the Caribbean region.

Weathering is often quite rapid and complete because of the high temperature and rainfall, resulting in clay-textured soils with a clay content of 35-40% or more. Clayey soils developed from sedimentary materials are widely distributed throughout the region (Holder and Griffith 1983), and the nature of the clay is quite variable (Warken-

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[1] The topic was introduced for discussion by D.G. Faris in the absence of the authors.

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ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Adaptation of chickpea and pigeonpea to abiotic stresses. Proceedings of the Consultants' Workshop, 19-21 December 1984, ICRISAT Center, India. Patancheru, A.P. 502324. India: ICRISAT.

tin 1982). The major orders into which the clayey soils are classified (Smith 1983) are Vertisols, Mollisols, Entisols, and Inceptisols (in particular, the Andepts).

The loamy soils with a clay content between 30 and 35% exhibit increasing plant-available water-holding capacity and compressibility with increasing clay content. Major soil orders for loamy soils in the Caribbean region are Inceptisols, Ultisols, Oxisols, Entisols, and Alfisols (Smith 1983).

The sandy loams and loamy sands developed from geologically similar sandstone and siltstone are distributed throughout the lower reaches of the Caribbean, as in the Guyanas and in Trinidad and Tobago. The soils are coarse to medium textured and fall in the major soil orders of Ultisols, Oxisols, and Entisols (Smith 1983). In Belize, there are large areas (approximately 160000 ha) of mature soils derived from quartz-rich, alluvial, old coastal sand deposits. These soils range in texture from gravelly nearer the sediment source (in the west) to gritty and silty clays (to the east) and are classified as Ultisols, although some Vertisols are also present (McKenzie 1977).

Physical and Physicochemical Characteristics

Vertisols, Inceptisols, Entisols, and Mollisols have deep profiles and are primarily used for the cultivation of sugarcane (*Saccharum officinarum*) and rice (*Oryza sativa*). Entisols and Inceptisols are younger soils occurring on coastal fringes, river deltas, and current flood plains. Some of the Mollisols in the upper reaches of estuarine mangrove swamps are "acid sulfate soils," which are difficult to manage or reclaim through drainage.

The most extensive clay soils in the region are Vertisols, which have unfavorable soil-water relationships. Physical and chemical properties related to genesis and structure are well described by Ahmad (1983). Montmorillonite is the dominant clay mineral and these clay soils have very slow internal drainage. The water-retention capacity of these soils is quite high, which can significantly reduce rooting depth and root proliferation of grain legumes. Fine clay (<0.2 mm) can constitute >80% of the clay fraction and, with the high content of montmorillonite, the clays become hard and impermeable in the drier areas and are very difficult to till. On drying, the soils shrink markedly and, following slight subsidence, wide cracks appear on the surface. On rewetting, these soils imbibe large quantities of water, swell, and become cohesive and sticky. The importance of these cracks and their closure in respect to aeration, drainage, root penetration, and self mulching has been described (Hardy and Derraugh 1947). Land preparation is, therefore, restricted to short periods when the soil moisture condition is favorable.

The field behavior of clay-textured soils in the remaining orders (Mollisols, Entisols, Inceptisols) depends upon properties related to the nature of clay minerals and the content of organic matter. Andepts have high organic matter (Griffith et al. 1984) and iron oxide content (Ahmad and Prashad 1970) and, although they have a clay texture, they behave as extremely "stable structured" loams.

Loam soils developed on flat alluvial deposits behave similarly to clay soils. Soils on hillsides are shallow (0-20 cm deep) and erodable; they have poor structure and low nutrient levels, especially in high-rainfall areas. Surface crusting is a feature in soils with large amounts of micaceous material. Many of the loam soils on slopes in Trinidad, however, are of low erodibility (Lindsay and Gumbs 1982). This may be due to the particular local cropping sequences or multiple-cropping systems that keep the slopes under a continuous crop cover. This aspect of soil management and erosion control needs further study.

The sandy loams and loamy sands with a coarse structure down the profile, as in the case of Entisols and some Oxisols, have an efficient internal drainage. However, in many of these soils, particularly the Ultisols, there is an increasing clay content (generally kaolinite) in the subsoil, which results in poor internal drainage and restricts root penetration. Encrustment at the surface may be a limitation to the establishment of seedlings and proper plant stands on these soils.

Chemical Characteristics

Clay and clay loams are relatively more fertile than sandy soils in the Caribbean region. Soils derived from marine origins are not extremely weathered (as in the Guyanas and Surinam) and provide a useful supply of essential plant nutrients other than nitrogen.

Although nitrogen deficiency can be ameliorated through application of urea or ammoniacal fertilizer, the efficiency of N utilization is very low. Nitrogen losses may occur through volatilization (on soils of high pH in regions with high evapotranspiration), denitrification (due to excess moisture leading to temporary anaerobic conditions or surface crust formation), or chemical fixation by clays especially where 2:1 lattice soil clays predominate. Leaching losses could be substantial under conditions that favor nitrification or when nitrate fertilizers are applied (Ahmad et al. 1983).

Legumes are important in soil fertility and crop management because of their ability for symbiotic nitrogen fixation. However, the low yield levels of cultivated legumes are a matter of concern in the Caribbean region. Increasing productivity through intensive cultivation of land is being explored, using suitable cultivars and applying fertilizer where it is traditionally not applied. However, the responsiveness of pigeonpea to fertilizers in the Caribbean region is still an open question.

Traditional pigeonpea cultivars do not readily respond to fertilizer application either in dry matter or grain yield (Rojoa 1980). In Trinidad, however, a significant 70% increase in grain yield of a dwarf pigeonpea cultivar G 1274A was reported when 20 kg N ha^{-1} was applied (Fig. 1). Also a grain yield increase of 25% was reported in dwarf pigeonpea grown on Inceptisols in response to application of 224 kg ha^{-1} of N, P_2O_5, and K_2O, each in five split applications, during the flowering period (Hammerton 1973). Application of P and K increased yield by 35-45% on the island of Marie-Galante(Sallette and Courbois 1969).

On the contrary, several workers have reported lack of response to straight or mixed fertilizer application in pigeonpea on soils in the Caribbean region. No significant yield advantage was observed when straight and mixed fertilizers were applied to cultivar UW 17 as a single dose 4 weeks after planting (Weir 1979). Again, no significant increase in yield was observed when ammonia was applied to Khaki variety on a Mollisol or in Kaininegro variety on an Oxisol (Landrau and Samuels 1959). Also no response was observed when mixed fertilizers (N at 43.5 kg ha^{-1} mixed with P, K, Ca, and Mg) were applied to Khaki variety on an Oxisol (Pietri et al. 1971). Small effects of N, P, Mo, and lime application were reported, however, on the growth and yield of pigeonpea in Trinidad (Dalal and Quilt 1977). Although grain yield increased slightly as fertilizer and lime application levels increased, a significant increase was observed in dry-matter production in 6-week-old plants only at the highest level of P application (250 kg ha^{-1}). The NxP interaction was significant because of increased absorption of N due to addition of P.

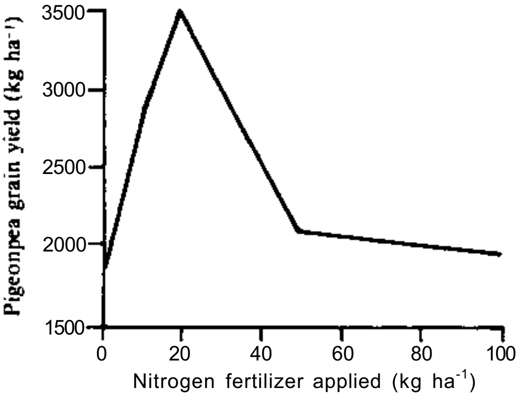

Figure 1. Effect of fertilizer-N on grain yield of pigeonpea G 1274A on River Estate Series (micaceous fine textured loam; Inceptisols). (After Table 6 of Dalai 1974; Dalai and Quilt 1977).

It is possible that pigeonpea may respond to fertilizer application when:

1. The geometry of the root system is altered through breeding dwarf varieties so that the major part of the root system is in the top 20-cm layer of soil (Edward-Hendry and Spence 1979; Griffith et al. 1984) where most of the applied fertilizer is. The increased nutrient concentration in the rooting zone is more likely to induce nutrient responses. This is in contrast to the feeding habit of traditional cultivars, in which the nutrients, particularly P, become increasingly available from greater depths as the root grows (Nye and Foster 1961).
2. Many of these soils are deficient in P and N, and P is considered to be the most limiting nutrient to legume production in the tropics (Fox and Kang 1977). Availability of P is affected by the soil pH and also by P fixation in the soils of the Caribbean region (MacFarlane 1974). Foliar application of N and P to overcome deficiencies is recommended in the tropics (Fox and Kang 1977); on Oxisols in Puerto Rico, however, this was not found to increase plant height, protein content, seed weight, or seed/pod ratio of the pigeonpea cultivars Khaki and 28-bushy (Feliciano et al. 1977).

Investigating the effect of different carriers of N fertilizers (NH_4Cl, $NaNO_3$, $CO(NH_2)_2$, and

NH_4NO_3) at the rate of 50 kg N ha^{-1} in one single application at planting on pigeonpea on a kaolinitic loam Ultisol, Rojoa (1980) found that urea gave better plant growth, more uptake of N prior to flowering, and a 28% increase in seed yield over the control. He further found that application of 25 kg N ha^{-1} as NH_4NO_3 at sowing or 40 days after sowing resulted in improved growth and yield. Applications of N later than 40 days increased dry matter, but it was at the expense of grain yield.

The evaluation of micronutrients essential for the growth of grain legumes has been limited in the Caribbean region. In general, micronutrient deficiencies do not seem to be a major fertility problem at this stage (Fox and Kang 1977), except in areas adjacent to the ocean (Ahmad 1984). The lack of response to micronutrient fertilization in grain legumes may be because of the low yield levels due to other growth limitations. One possible exception is zinc, which does not have a specific role in the legume-*Rhizobium* symbiosis (Franco 1977). But zinc is a widespread nutrient deficiency in Oxisols and may be in short supply in some Ultisols (Rojoa 1980) and Vertisols (Munro 1984).

Biological Nitrogen Fixation

Recently, there have been major inputs into research on nitrogen fixation at the Department of Soil Science, University of the West Indies, Trinidad. The Overseas Development Administration of the United Kingdom is supporting work on pigeonpea; the International Development Research Centre of Canada supports work on forage legumes; and Cornell University, USA, supports work on other grain legumes. Forty-five strains of indigenous *Rhizobium* have been identified in soils of a wide range of textures.

The contribution of rhizobia to improvement of the N economy of Caribbean soils cropped with legumes has not yet been well quantified, but some conclusions can be drawn for certain crops. In pigeonpea, small doses of fertilizer N increase nodule weight, nodule number, and nitrogenase activity (Donawa and Quilt 1981), suggesting that there is some scope for improving the symbiosis. It has been confirmed that, in Caribbean soils, pigeonpea is nodulated by indigenous promiscuous *Rhizobium* strains of the cowpea miscellany. Cultivars grown on the same soil series differ in their association with particular *Rhizobium* strains; local varieties select markedly different *Rhizobium* strains than the introduced varieties. There is, therefore, considerable variation in the degree of effectiveness of symbioses. It has been shown that nodule numbers decline at or shortly after the reproductive phase and during periods of moisture deficits (Ariyanayagam 1975), but the effects of soil water on nitrogen fixation have not been thoroughly investigated. With cowpea on various ameliorated soils, it may not be necessary to inoculate (Mughogho and Lowendorf 1979) since the early effects of inoculation on nodule number disappear, and eventually the uninoculated treatments may even outyield the inoculated treatments (Graham and Scott 1984).

Soil Acidity and Aluminum Toxicity

Extensive areas in the Caribbean region have become acidic due to weathering and leaching in a tropical-humid climate. Clay and clay loam-textured soils show a wide range of soil reaction and can be quite acidic (Holder and Griffith 1983; Ahmad 1984). Exchangeable aluminum does not usually contribute to the infertility of acid clays and clay loams. In sandy loams and loamy sand tropical soils (Oxisols, Ultisols, and Alfisols) with pH values lower than 5.0, exchangeable aluminum may increase to 80% saturation. In acid clay or clay loam soils at such pH values, aluminum saturation would be no more than about 20-25%.

In the Caribbean region—particularly in the Guyanas, Trinidad, and Puerto Rico—there are large areas of sandy loams to loamy sands (Oxisols, Ultisols, and Alfisols) of low native fertility and high acidity but with physical attributes favorable for crop production. However, the deficiency of Ca, Mg, and K (due to a lack of primary minerals) severely limits sustained high yields of food grain legumes. Research conducted in Puerto Rico revealed that even when the surface soil is adequately limed, subsoil acidity limits crop yields because root proliferation in the subsoil is prevented (Bouldin 1978; Wolf et al. 1978). Thus subsoil moisture is unavailable to the crop. The stored subsoil water is very important for crop growth in this region as there are several consecutive days without rain during most growing seasons (Bouldin 1978).

Salinity and Sodicity

The development of salinity under permanent irrigation is mainly a function of the quality of irrigation water and soil textural class. On the lighter textured sandy loams and loams, use of irrigation water in the EC range of 2.5-3.0 mmhos cm^{-1} resulted in marginal increases in salinity levels (Miller 1984). On heavier textured clays and clay loams, however, use of such water resulted in saline and salinc-sodic conditions with increases in levels of exchangeable Na and Mg, and a concomitant decrease in exchangeable Ca (Miller 1984). In Barbados, the entire Scotland District (about one quarter of the area of the island) is characterized by saline-alkaline soils with an EC >5 mmhos cm^{-1}, an ESP ranging between 20 and 40% and an SSP at all profile levels of 97% (Webster 1984). The upper ranges of soil pH values vary between 8.0 and 8.5.

Rainfall Patterns

The distribution of rainfall is bimodal, with two distinct wet seasons and two dry seasons in some of the larger territories (e.g., the Guyanas and Belize). There is a marked dry season and a distinct wet season in other territories, particularly in the islands (e.g., Trinidad). Gumbs (1982) has described the rainfall distribution patterns of Guyana and Trinidad. Influences include the mountain ranges, rainfall, shifts in the prevailing winds (from northeast in the dry season to east or east-southeast in the wet season), and the activity of the Intertropical Convergence Zone (ITCZ) which produces intense rainstorms and hurricanes that seriously affect agricultural production in some territories. In the Guyanas, wet seasons are generally from November/December to January and from May to July, dry seasons are from February to April and from August to October/November. Annual rainfall ranges between 1600 and 1700 mm in coastal areas toward the east, and increases to > 2500 mm toward the more mountainous northwest. Daily rainfall distribution is influenced by convectional activity and is greatest at midday. The intensity of short-duration rainfall can be as high as 100 mm h^{-1} (Gumbs 1982).

Climate and Crop Growth

Except for rainfall, the elements of climate (e.g., air temperature, humidity, wind, etc.) do not vary significantly over the agricultural areas of the island territories. In Trinidad, rainfall is usually quite heavy at the beginning of the wet season and tapers off toward the end of August (Fig. 2). This is a period of uninterrupted crop growth because the soil nitrogen mineralized during the dry season is available, daylength is optimum, and soil moisture is abundant as rainfall exceeds evapotranspiration (approximately 125 mm $month^{-1}$). Cloud cover partially reduces the quantity of solar radiation. The unpredictable rainfall and its distribution causes periods of waterlogging, which reduces yield during this period. Soil moisture and aeration conditions are favorable for growth during September and/or October. Rainfall in the months of November and December is vital where rainfed agriculture is normally practiced. It provides enough stored soil water to allow a period of uninterrupted growth until April in the dry season (see Fig. 2), during which evapotranspiration exceeds rainfall. However, heavy rainfall in November and December may interrupt crop growth or limit land preparation practices. In December, daylength is at its shortest and crops responsive to photoperiod (e.g., pigeonpea, sugarcane) exhibit photoperiodic effects. During February and March, cooler night temperatures allow a greater amplitude in diurnal temperature variation, which has been known to cause other physiological effects on crop growth.

Showers are common in the dry season and only rarely do completely rainless months occur. Drought periods can interrupt plant growth during this time of the year.

Drought Stress

The climatic and edaphic adaptability of pigeonpea has been reviewed by Akinola et al. (1975) and El Baradi (1978). It is generally accepted that the crop has wide adaptability and thrives in marginal environments where most other legumes fail. While such generalizations may be valid in relative terms, there is little doubt that environmental stresses limit the productivity of pigeonpea. The basis for adaptation to stress environments and the genotypic variability in adaptation have neither been sufficiently researched nor adequately evaluated in the Caribbean. The reasons for the inadequate research attention that this crop has received are the temporary nature of some stress environments, limited areas of occurrence, limitations of research inputs, and the fact that the crop and its problems are largely the concern of backyard growers and small farmers.

A measure of success has been achieved, however, in dealing with short-term drought problems. The main thrust of the pigeonpea improvement program

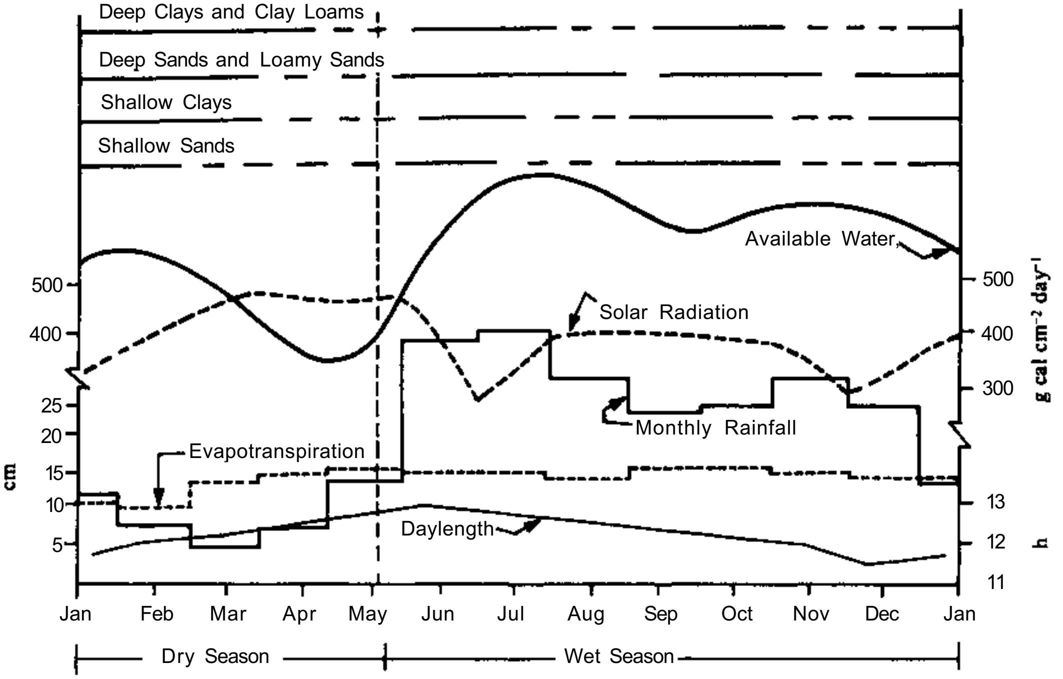

Figure 2. Periods of uninterrupted crop growth in Trinidad on soils of varying texture (unpublished, F. Hardy 1976).

in the Caribbean during the past few years has been on combining the determinate nature of the crop with earliness and insensitivity to temperature and the effects of daylength. Cultivars are now available which complete their life cycle in 4 to 5 months, compared to 8 to 10 months required for the long-duration traditional cultivars. Rainfall in Trinidad and the wetter islands is spread over a period of 7 to 8 months, and reliable growth periods during that span are available (see Fig. 2). Early varieties matched to such periods have often given yields of 4000 kg ha^{-1} of unshelled peas in semicommercial plantings. Thus, yield in the wetter islands can be maximized through the use of early-maturing cultivars and by choosing sowing dates that would avoid lengthy periods of drought and high evaporative demand, as well as high temperatures during flowering and pod filling. In the drier islands, early sowing, at the beginning of the rainy season, would help the crop escape drought during flowering and pod filling.

Prolonged drought has been shown to affect the growth and yield of early cultivars. Irrigated crops of UW 17 and UW 26, two early-flowering cultivars planted during the dry season on a clay loam in Jamaica, were taller than the unirrigated crop: UW 17 by 32% and UW 26 by 38% (Weir 1979). Under long-day conditions, the irrigated crop of both varieties was 13% taller. Both cultivars produced significantly higher dry matter under irrigation. It was also reported that supplemental irrigation on Inceptisols increased the yield of UW 17 and UW 26 during the Trinidad dry season by more than 2 t ha^{-1} at a planting density of 200 000 plants ha^{-1} (Keating and Hughes 1981). Further increases in density by integrals of 100 000 plants ha^{-1} up to 600 000 plants ha^{-1} gave yield increases of 0.16 t ha^{-1}, whereas imposition of moisture deficit reduced yield by 1.41 t ha^{-1}.

Throughout the Caribbean, short spells of intermittent drought during the rainy seasons, particularly on lighter soils such as Ultisols, are a regular feature. Alternating with these spells are periods of elevated water table after heavy rainfall. Root development, probably conditioned by the water table, seldom penetrated beyond the top 45 cm of the soil (Edward-Hendry and Spence 1979). Thus the two extremes of water stress—soil moisture deficit on the one hand and high moisture content on the other—

affect extensive areas of the heavier-textured soil on which pigeonpea is a potential crop in the Caribbean region.

During recovery from prolonged drought, a rapid shoot growth from the axillary buds occurs, reestablishing the photosynthetic surface with the eventual resumption of reproductive development (F.B. Lopez, University of West Indies, personal communication). Regrowth after drought stress could be rapid if storage reserves are available to supplement current photosynthate (Setter et al. 1984), and such regrowth might be desirable when drought occurs in early stages. But if the drought occurs late in the season, then channelling current photosynthate toward seeds might be preferable to regeneration of growth. For instance, moisture deficit on unirrigated River Estate loam in the Trinidad dry season was thrice as severe during the reproductive growth phase as in the vegetative phase for the early-maturing varieties (Keating and Hughes 1981). Thus it would appear that partitioning of photosynthate, particularly in the early-maturing cultivars, may need closer scrutiny. This approach of altering dry-matter partitioning has been used effectively to evolve cowpea cultivars adaptated to drought (Hall and Grantz 1981).

Drought during the early vegetative phase may not be excessively harmful if the stress does not persist into late vegetative growth. Experience on the clay loams and loams in Trinidad, and to a limited extent in the intermediate savannas of Guyana (sandy loams and loamy sands), suggests that mild drought in the early vegetative phase may help develop a deeper and more vigorous root system.

The juvenile growth of pigeonpea is very slow, and prolonged drought at that stage considerably impedes development, predisposing the crop to leaf hopper and field cricket attacks in some of the Caribbean countries. Variability for seedling vigor has not been found in the Caribbean, and little is known about the slow growth rate during the first 4-6 weeks. If the key to drought adaptation in the early vegetative phase is rapid rejuvenation, the physiology of seedling growth has to be critically examined.

Physiological Responses to Drought Stress

Although pigeonpea is widely thought to be a drought-tolerant plant, the mechanism of drought tolerance, which should be the basis for adaptation, has not yet been clearly established. Leaf-water potential and stomatal resistance were examined in both potted and field-grown pigeonpeas in an Inceptisol (Taitt and Spence 1976). The two parameters were correlated with severe moisture deficit in potted plants, but were not so on field stands under moisture deficits.

Although the pressure chamber technique is used successfully to determine plant water status in a number of plant species in the laboratory and field, there are problems of end-point recognition in pigeonpea (F.B. Lopez, University of West Indies, personal communication). The end point was obscured due to bubbling, which increased rapidly to a froth as pressure was increased. In some instances, bubbling commenced even before pressure was applied, but in most cases it occurred in well-watered plants at the start of pressure increase. In water-stressed plants, bubbling occurred at higher chamber pressures. The problem was further complicated by the appearance of an exudate at the cut surface. It is possible that secretory cells and ducts may be involved in the initial exudation (Bisen and Sheldrake 1981), but the ease with which it occurred might indicate the presence of stored water.

Indications are that the crop achieves drought resistance through avoidance or escape. Hughes et al. (1981) observed a reduction in leaf area in response to water stress. Also, increases in leaf diffusive resistance, paraheliotropy and root/ shoot ratio have been observed in response to moisture deficit (F.B. Lopez, University of West Indies, personal communication). These responses often occur at the onset of drought. If drought persists, reproductive structures may exhibit escape symptoms of senescence and the crop's phenology may adjust to the stress environment. Under both situations, the resumption of a favorable environment prior to permanent wilting triggers a second lease on life. Genotypic variability for the rate of rejuvenation has been observed (F.B. Lopez, University of West Indies, personal communication).

Heat Stress

Drought stress is usually accompanied by high temperatures, and the effect of this on senescence of reproductive structures has not been studied in pigeonpea. Varietal differences for pod set in cowpea were reported during the hot weather in the Imperial Valley, California (Warrang and Hall 1983). Further studies in growth chambers, while confirming varietal differences in heat tolerance at flowering, showed that susceptibility to high temperature was associated with male sterility from low pollen viability and indehiscent anthers. A preliminary study with pigeonpea in Trinidad has shown that heat stress could induce substantial senescence of reproductive structures (R.P. Ariyanayagam, unpublished data).

Management Strategies to Alleviate Soil and Water Problems

Soils prone to drought where crop production is limited under rainfed agricultural systems are not widespread in the Caribbean region. However, their occurrence in several island territories (e.g. Antigua, Barbados, the Virgin Islands, Jamaica) and on the mainland territory of Belize limits production in those regions. Many such drought-prone areas are avoided for crop cultivation or are used to grow forages. In Jamaica, however, attempts have been made to irrigate about 35 700 ha of drought-prone saline areas for the continuous production of sugarcane. Using sugarcane as the indicator crop, the application of mulches (sour grass, bagasse, poultry manure) in combination with gypsum at 10 t ha^{-1} on a ridge-and-furrow system of cultivation effectively reclaimed such soils; it resulted in more extensive root systems and greatly increased yields. Salts moved upward under capillary forces resulting from surface evaporation and were flushed from the surface by subsequent rainfall (Webster 1984).

Water management strategies employed in the Caribbean region for areas where the soil moisture content is above field capacity for prolonged periods are as follows: (1) Cambered beds (4 to 8 m wide); (2) ridges (0.75 to 2 m wide) on flat land or along cambered beds; (3) flatbeds (1.5 to 4 m) with box drains between beds (i.e., drains that are square or rectangular in cross section); (4) ridges and furrows, or flatbeds, with field drains between beds (Lindsay et al. 1984). The most effective method of removing surface water on clays and clay loam soils requires grading of fields and a field layout of ridges and furrows on narrow 3 to 4 m beds (L.A. Simpson, personal communication). Experimenting on Inceptisols in Trinidad with cowpea, Gumbs et al. (1982) showed that when soil moisture was around field capacity, there was an almost linear increase in the concentration of N and P in the leaves up to 56 days after planting, which coincided with fruit development. However, between October and December, temporary flooding, which may occur for 12 to 24 hours at about 30 days after seeding, results in a notable decline in N and P concentrations in the leaves. The benefits of using vegetative mulches to conserve moisture and N fertilizer, particularly in the dry seasons, have been confirmed (Nkrumah 1982). In the wet seasons, application of mulches results in waterlogging and creates anaerobic soil conditions.

Bouldin (1978) has suggested strategies to minimize the limitations imposed by subsoil acidity on loamy sands and loams. These include: (1) avoidance of areas for immediate development where subsoil acidity is severe and the use of tolerant crops; (2) the leaching of sufficient lime (2 to 5 years) into acid subsoils to promote root growth; (3) selection of cultivars with appropriate growth duration, which, with proper planting date, will often avoid periods of most likely moisture deficit, and (4) selection of locations where rainfall distribution and soil water-storage capacity will minimize dependence of crops on subsoil water.

For increased legume production in the Caribbean, a greater research emphasis should be placed on crop genetic improvement for tolerance or avoidance of stress. Alleviation of many of these stresses and reclamation of the land is expensive and requires considerable resources (Downton 1984). Such reclamation strategies may be suitable for large-scale operations. With increasing cost of energy inputs, alternatives need to be found, which are more practical than strict engineering solutions and which suit small farmers in the Caribbean region (Downton 1984; Lindsay et al. 1984).

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Soil and Climatic Stresses on Chickpea Production in Ethiopia

Tamirie Hawando[1]

Abstract

Ethiopia is the most important chickpea-producing country in Africa, commanding more than one-third of the total area devoted to chickpea cultivation on the continent. In terms of chickpea yields, Ethiopia ranks third, after Egypt and Sudan where the crop is irrigated. Chickpea in Ethiopia is grown in areas with annual rainfall ranging between 950 and 1800 mm and altitudes ranging between 1400 and 2300 m above mean sea level. The extreme variations in the geomorphic features of Ethiopia are responsible for wide differences in climate, vegetation, geological formations, and soil types. Chickpea in Ethiopia is grown mostly in poorly drained and waterlogged Vertisols in the highland regions of the country. The potential to increase average chickpea yields is very promising in Ethiopia through well-planned and executed research and by selecting improved, high-yielding chickpea genotypes that are tolerant to soil and climatic stresses.

Introduction

Chickpea (*Cicer arietinum* L.) is an important pulse crop of Ethiopia. It is cultivated at altitudes ranging from 1400 to 2300 m(Geletu Bejiga 1980), in a region of rugged topography where wide geomorphic variations are associated with contrasting soil types and ecological zones (Mohr 1964; Murphy 1968; Westphal and Westphal-Stevels 1975; Tamirie Hawando 1974, 1975, 1984). Some of the factors limiting chickpea production are drought, waterlogging on plateaus and some intermountain valleys, salinity and alkalinity problems in irrigable river valleys, and frost at altitudes above 1900 m (UNDP 1965; Murphy 1968; Mesfin Abebe 1981).

As it is written by a soil scientist, this paper will lay more emphasis on soil and climatic factors than on the ecological or physiological aspects of chickpea production.

Climatic Environment

Average rainfall distribution in Ethiopia is shown in Figure 1. Nearly one-third of the country receives less than 450 mm a^{-1} of rainfall, and another one-fifth between 450 and 950 mm a"'. In the 450-950 mm annual rainfall zone, the erratic distribution of rainfall, rather than total rainfall, is responsible for partial or total crop losses resulting in frequent food deficits in the region. In the 150-450 mm annual rainfall zone, the erratic distribution of rain, coupled with total failure of rain in some years, causes a total loss of grasses and bush, and consequently of livestock (LUPRD 1983). Problems of salinity, alkalinity, and cyclic drought, chronic in the two zones receiving less than 950 mm annual rainfall, should be tackled by harnessing rivers and exploiting groundwater reserves for irrigation.

Chickpea is produced primarily in the 950-1800 mm annual rainfall zone, where the crop is grown on residual soil moisture, particularly in the waterlogged valleys and highland plateaus. The area of rainfed crop production is shown in Figure 2.

Production Statistics

Data for the average area harvested and yield of pulses for 14 major pulse-growing countries of

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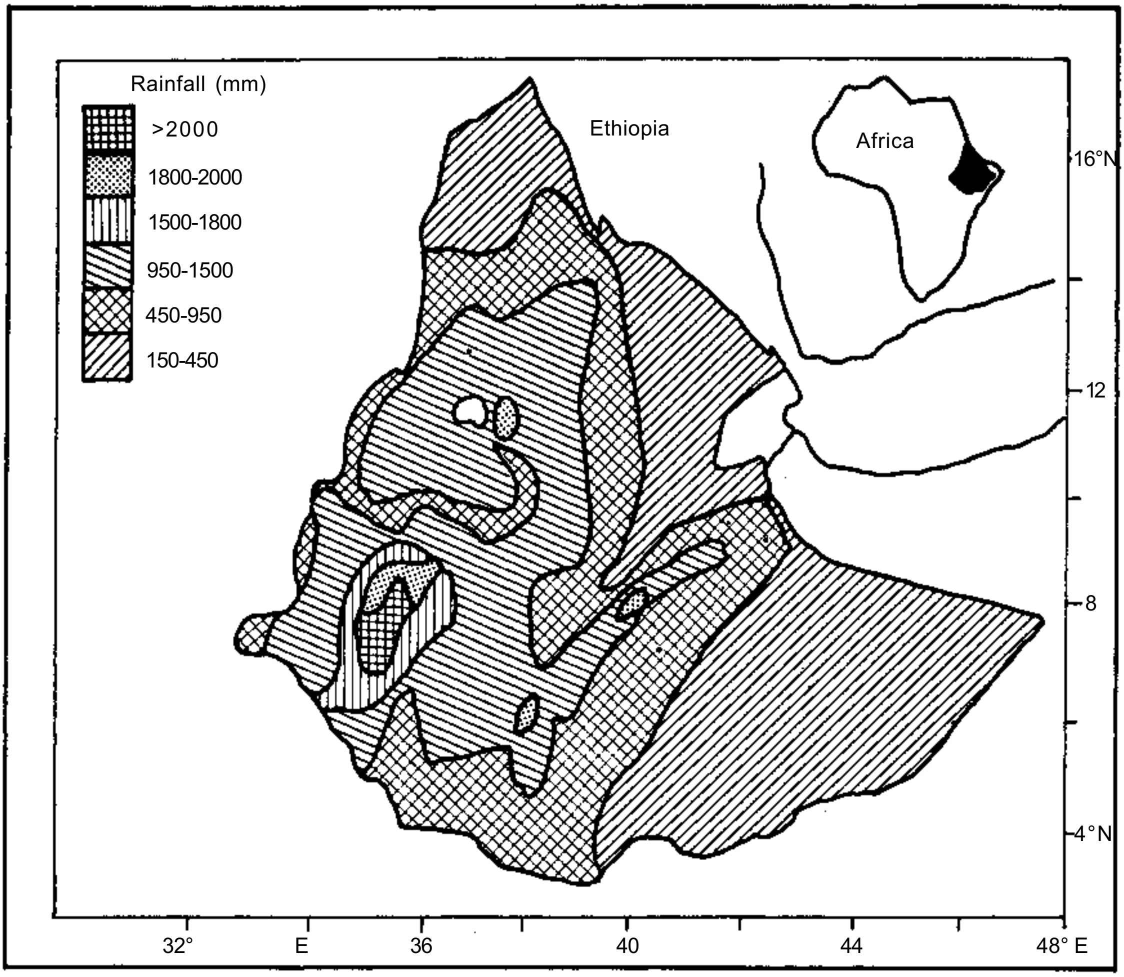

Figure 1. Average annual rainfall distribution in Ethiopia.

Africa are given in Table 1. Average yields in African countries are lower than the world average. Between 1974 and 1982 Ethiopia ranked third, next to Nigeria and Niger, in the total area of pulses harvested. But the yield of pulses in Ethiopia was 3-5 times greater than those in Nigeria and Niger. The highest yields were obtained in Egypt (1800-2000 kg ha^{-1}), followed by Sudan (1000-1100 kg ha^{-1}), and Ethiopia (700-1100 kg ha^{-1}). In Egypt and Sudan, pulses are irrigated, whereas in Ethiopia they are grown on residual soil moisture.

Data for the area harvested and yield of chickpea for 10 major chickpea-producing countries in Africa are given in Table 2. Chickpea yields in African countries were generally slightly higher than the world average. Ethiopia ranked first in area under chickpea, followed by Morocco and Tunisia. The highest yield of chickpea was recorded in Egypt (1600-1800 kg ha^{-1}), followed by Sudan (900 kg ha^{-1}) and Ethiopia (600-800 kg ha^{-1}). Chickpea in Egypt and Sudan is irrigated.

The area cultivated and yields of the five major pulses grown in Ethiopia are given in Table 3. Chickpea ranked first in area among the five pulses grown in Ethiopia until 1973-74; thereafter it was replaced by horse bean. The reason for the decline in both area and yield of chickpea during the 1974-75 and 1975-76 crop seasons could probably be the replacement of chickpea by high-yielding pulses, such as horse bean, and by other cereal crops grown in the

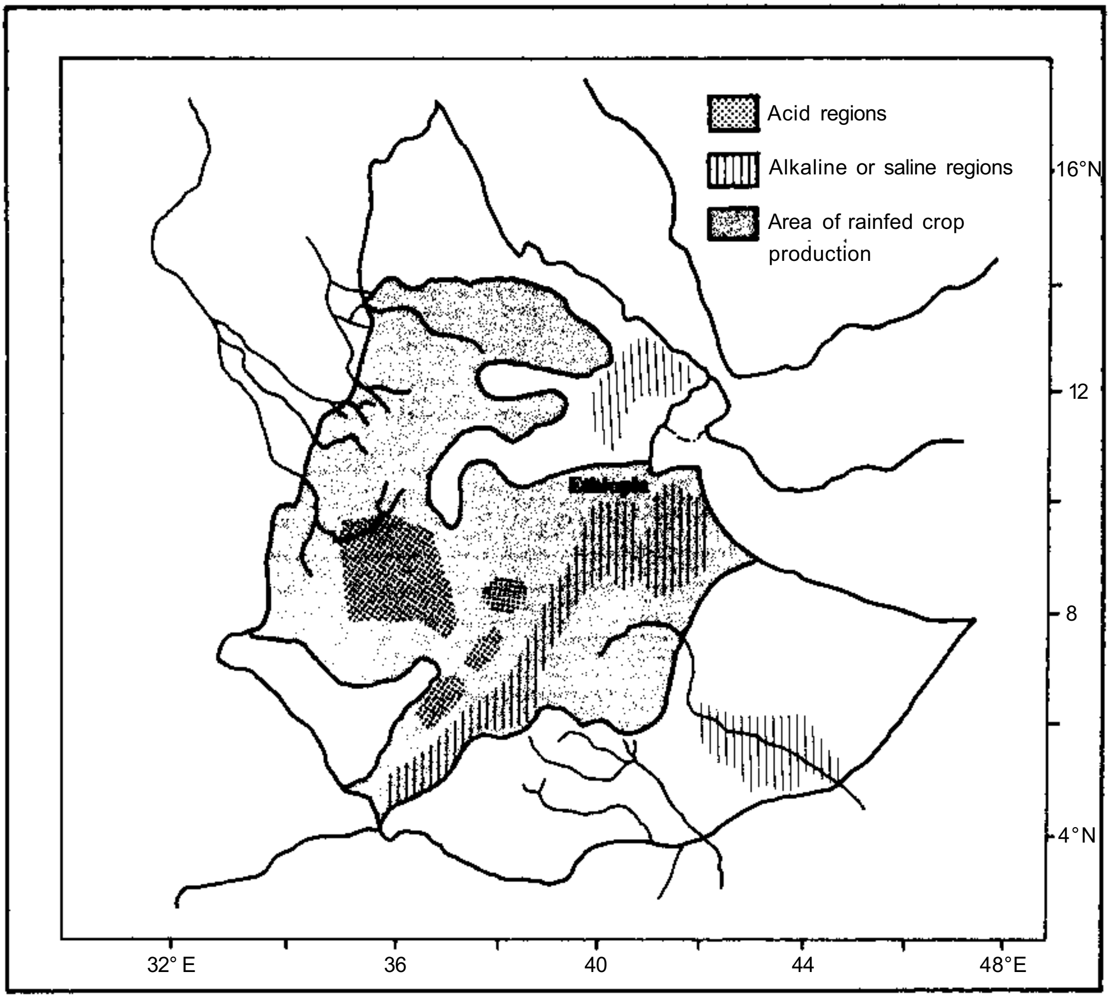

Figure 2. Areas of Ethiopia with acid or alkaline/saline soils and areas of rainfed crop production. (After LUPRD 1983).

region. In general, the area under pulses was significantly reduced in the 1975-76 crop season from that in previous seasons.

The primary and secondary chickpea-growing regions in Ethiopia are shown in Figure 3. Data for the cultivated area and yields of chickpea and lentil grown in three major pulse-producing regions in Ethiopia are given in Table 4. The potential for improving yields of chickpea and lentil is very high, as indicated by the wide range of yields obtained in the three major producing regions in Ethiopia. The geographic distribution of chickpea production in Ethiopia generally coincides with the 950-1500 mm rainfall zone (see Figs. 1, 3) and the occurrence of Vertisols (Fig. 4).

Average yields of two improved chickpea varieties and one local variety grown in five locations in Ethiopia are shown in Table 5. All three varieties were grown on Vertisols under residual moisture conditions, except at the Melkassa II station where the soils are of volcanic ash origin and the chickpea was grown under irrigation. The potential of chickpea production in Ethiopia under both residual moisture and irrigated conditions seems promising.

Table 1. Area harvested and mean yield of pulses for 14 major pulse-producing countries in Africa, Africa as a whole, and the world, 1974-1982 (FAO 1982).

	Area harvested ('000 ha)[1]				Yield (kg ha^{-1})			
Country	1974-76[2]	1980	1981	1982	1974-76[2]	1980	1981	1982
Burkina Faso	458	475F	475 F	475 F	359	368	368	375
Burundi	290	298 F	302F	305 F	627	706	711	720
Egypt	168	145	138	139F	2058	1965	1828	1918
Ethiopia	874	867	897	911F	727	1056	1090	1100
Kenya	613	550F	550F	560F	476	418	436	446
Malawi	284	300F	302F	305 F	662	683	685	692
Morocco	570	408	325	490	953	606	284	472
Niger	898	I 124	1242	1462	222	247	236	209
Nigeria	4127	4115F	4115F	4318F	205	219	219	218
Rwanda	266	276 F	278 F	278 F	747	808	813	817
Sudan	70	75F	76 F	77 F	1067	1115	1 114	1 114
Tanzania	433	498 F	498 F	515F	439	454	434	435
Uganda	593	313F	401	492	635	735	845	839
Zaire	237	252	256 F	260F	609	550	547	543
Africa	11617	11468	11673	12412	455	462	457	458
World	63 576	62679	63813	66 295	664	645	665	674

1. F = FAO estimate.
2. Averaged by year.

Table 2. Area harvested and mean yield of chickpea for 10 major producing countries in Africa, Africa as a whole, and the world (1974-82) (FAO 1982).

	Area harvested ('000 ha)[1]				Yield (kg ha^{-1})			
Country	1974-76[2]	1980	1981	1982	1974-76[2]	1980	1981	1982
Algeria	33	42 F	43	43 F	666	376	381	383
Egypt	3	6U	8U	9F	1 681	1 833	1 625	1 625
Ethiopia	166	172	249	170F	603	854	793	882
Libya	ND[3]	ND	ND	ND	556	667	682	699
Malawi	23	25 F	25 F	25 F	676	720	720	732
Morocco	119	66	32	53U	774	681	188	755
Sudan	2	3F	3F	3F	945	933	933	933
Tanzania	33	27F	27F	29F	242	278	278	276
Tunisia	41	50F	50F	49 U	553	600	640	978
Uganda	6	3	4	5	392	333	500	600
Africa	427	394	341	387	633	705	634	779
World	10 143	9552	8 966	10213	616	510	644	603

1. F = FAO estimates; U = Unofficial data.
2. Averaged by year.
3. ND = no data.

Table 3. Area cultivated and mean yield of five major pulses grown in Ethiopia, 1972-76 (MOA1979; Gelatu Bejiga 1980).

	Area harvested ('000 ha)				Yield (kg ha^{-1})			
Type of pulse	1972-73	1973-74	1974-75	1975-76	1972-73	1973-74	1974-75	1975-76
Chickpea (*Cicer arietinum* L.)	300	302	177	198	770	780	635	550
Common bean (*Phaseolus vulgaris* L.)	125	132	70	42	680	681	730	845
Field pea (*Pisum sativum* L.)	150	151	108	107	493	496	583	484
Horse bean (*Viciafaba* L.)	137	138	320	259	850	865	921	1175
Lentil (*Lens culinahs* Medic.)	170	172	116	56	430	429	390	480

Table 4. Area cultivated and mean yields of chickpea and lentil grown in three major pulse-producing regions of Ethiopia, 1974-79.[1]

	Chickpea				Lentil			
	Area ('000) ha)		Yield (kg ha^{-1})		Area ('000) ha)		Yield (kg ha^{-1})	
Region	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Shoa	55.8	45.1-66.3	510	450-670	45.3	25.5-65.2	550	350-820
Gondar	58.2	51.4-65.3	740	420-1100	12.1	7.9-18.8	650	310-900
Gojam	53.9	6.0-99.4	570	300-840	1.4	0.9-2.0	690	260-1180

1. Source: Raw data obtained from the Ministry of Agriculture, Planning and Programming Department (July 1979).

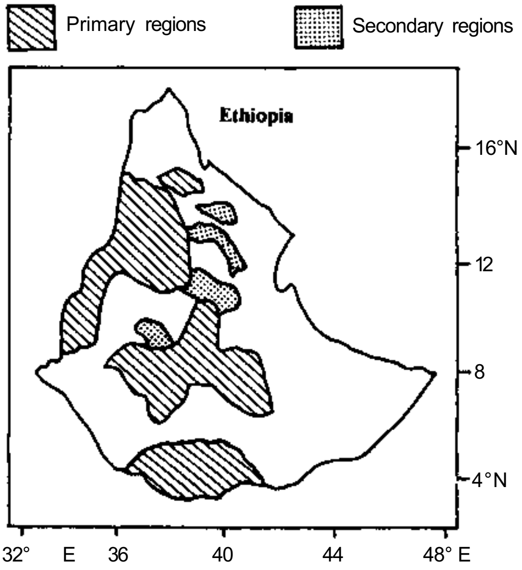

Figure 3. Regions of chickpea production in Ethiopia (Gelatu Bejiga 1980).

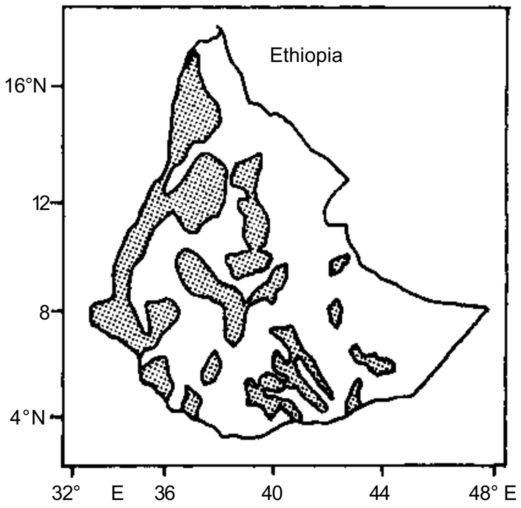

Figure 4. Distribution of Vertisols in Ethiopia (Tamirie Hawando 1984).

Table 5. Average yield (kg ha^{-1}) of three chickpea varieties grown in five locations in Ethiopia during the 1982 and 1983 crop seasons (Geletu Bejiga, personal communication).

Variety	Debre Zeit, Shoa (900 mm)[1]	Ginchi, Shoa (1000 mm)	Melkessa II, Nazreth[2] (600 mm)	Akaki,[3] Shoa (900 mm)	Sirinka,[3] Wollo (800 mm)
JG 62 x Radhey	2150[3]	2250	3400	2070	2410
H-54-I0 (local)	1540	2710	2750	2170	2570
850-3/27 x F 378	2330	2030	2420	2670	2810

1. Figures in parentheses indicate average annual rainfall at that location.
2. Under irrigation.
3. Data for 1983 only.

Table 6. Various estimates of percentage distribution of different soil orders(USDA) and soil units (FAO/UNESCO) in Ethiopia (Tamirie Hawando 1984).

		Land surface (%)			
USDA soil orders	FAO soil units	Donahue 1972[1]	FAO/UNESCO World Soil Map, 1974[1]	Westphal 1974	Tamirie Hawando 1982
Aridisols	Xerosols, Yermosols, Solonchaks, Salt flats	50	23	20	15
Entisols	Lithosols, Regosols, Arenosols, Fluvisols	25	34	27	26
Ultisols	Nitosols	6	14	2	9
Vertisols		19	4	15	17
Alfisols	Luvisols	-	4	10	6
Inceptisols	Cambisols, Andosols	-	21	25	23
Oxisols	Ferralsols	-	<1	1	2
Mollisols		-	-	-	2
Histosols		-	-	-	<1

1. Cited in Tamirie Hawardo 1982.

Soil Types

The extreme variations in the geomorphic features of Ethiopia are responsible for the wide diversity of climate and vegetation in the country. They have led to the occurrence of a wide range of soil types that differ from one another in major physical and chemical properties (Murphy 1968; Tamirie Hawando 1974, 1975, and 1984; Brehanue Debele, personal communication). The approximate distribution of different soil orders (USDA) and soil units (FAO/UNESCO) in Ethiopia is given in Table 6. According to more recent estimates (Tamirie Hawando 1982), Vertisols (17%) rank third in abundance, after Entisols (26%) and Inceptisols (23%).

Figures 3 and 4 illustrate how the geographic distribution of Vertisols in Ethiopia overlaps with the chickpea-producing regions in the 950-1600 mm rainfall zone. The Vertisols in the highlands of Shoa, Arsi, parts of Gojam, and Gondar are hydromorphic, and thus have waterlogging problems. At the end of the Ethiopian rainy season (June to August), the waterlogged areas are plowed and chickpea is sown during September. Chickpea grows and matures on the residual soil moisture both in nonwaterlogged and waterlogged hydromorphic Vertisols and/or other hydromorphic soils.

Some salient physical and chemical characteristics of the surface horizon of Vertisols of the major chickpea-producing regions in the Ethiopian highlands are given in Table 7. The texture of these soils is clayey, and the Debre Sina, Fitchie, Wolkitie, and Backo soils are susceptible to waterlogging. More than 77% of the surface soils in these regions are acidic (pH <6.5), except in the Dukam, Debre Zeit, and Modjo regions where the pH of the soil is neutral. Organic-matter and total nitrogen contents of some of these soils are low.

The available phosphorus in Ethiopian Vertisols is low to very low, and the crop responds well to phosphate fertilization. The available potassium in these soils is high, and no response to potassium fertilization was obtained in a number of major soil types in Ethiopia (Murphy 1968; Tamirie Hawando 1974, 1982; Tsedale Waktola 1983).

Variations among soil types in toposequence in a given landscape have led to significant differences in crop response to applied fertilizers. Data for selected physicochemical properties of two soils in the Ada Plains of central Shoa highlands are given in Table 8. The Gombore soils (Andosols) are reddish brown to brown and formed from scoraceous volcanic rocks. They are found on the foothill slopes of scattered volcanic hills and mountains in the Ada Plains. The Koticha soils (Vertisols) are found in waterlogged bottom lands surrounding the volcanic hills and knolls. The Gombore soils are sandy clay loams, very high in available phosphorus, high in total nitrogen and organic matter, and better drained than the clayey and poorly drained Vertisols. Phosphorus deficiency symptoms can be observed on chickpea growing on Vertisols in the Ada region, whereas no phosphorus deficiency is apparent on chickpea growing on adjacent Gombore soils.

Salinity, Alkalinity, and Acidity

The regions affected by salinity and alkalinity in Ethiopia are shown in Figure 2 (Murphy 1968;

Table 7. Some major physical and chemical characteristics of the surface horizon of Vertisols occurring in major chickpea-producing highland regions of Ethiopia (Murphy 1968; Samuel Geleta 1981; Tamirie Hawando 1984). Data are presented as % of total samples for each characteristic.

Highland region	pH (in H_2O)			Organic matter (%)			Total nitrogen {%)		Available phosphorus			Available potassium			Number of samples tested
	<5.5	<6.0	<6.5	<2	<3	<5	<0.15	<0.25	Low	Medium	High	Low	Medium	High	
Gondar	24	66	87	14	37	76	43	85	51	22	28	17	9	75	59
Gojam	65	85	96	6	12	58	18	76	80	11	9	14	11	75	80
Shoa[1]															
Debre Sina	10	54	97	4	7	87	J2	64	61	23	16	12	3	86	110
Fitchie	46	72	90	20	34	82	33	74	56	20	25	8	13	79	49
Wolkitie	3	37	78	28	57	96	61	89	59	22	18	0	0	100	76
Backo	64	72	79	21	33	92	64	96	90	3	8	0	22	78	78
Modjo	I	5	25	4	71	98	72	95	25	12	63	1	8	91	111

1. The soils of Shoa are listed by region for simplicity, but each extends from Addis Ababa to that region.

Table 8. Selected physical and chemical properties for two soil types occurring in Ada Plains, Central Ethiopia (Murphy 1968; Ayele Becherie and Tamarie Hawando 1974; Samuel Geleta 1981)

Soil type	Surface soil texture	pH (in H_2O)	Available phosphorus	Total nitrogen (%)	Organic matter (%)	Cation-exchange capacity (meq $[100g]^{-1}$)	Drainage
Gombore (Andosols)	Sandy clay loam	6.3	Very high	0.19-0.28	3.00-6.07	25.8-34.1	Well drained
Koticha (Vertisols)	Clay	6.8	Low	0.04-0.08	1.85-2.28	36.3-52.0	Partially waterlogged

Tamirie Hawando, unpublished data). These regions are found in lowland areas and the Rift Valley zone, where the potential for irrigation is high. With the introduction of irrigation schemes into these zones, a definite plan for reclamation of saline and sodic soils and better management of these soils can be formulated, coupled with proper layout of irrigation and drainage schemes.

Data for soil reaction (pH) of some soils of the Awash River Basin irrigation zone (in the Rift Valley) are given in Table 9. Most of the surface soils in this zone are mildly to moderately alkaline. The problem of sodium in these soils is more severe than was originally thought; it needs immediate attention for amelioration of the potentially productive lowlands of Ethiopia.

Chickpea is not grown in highly weathered Ultisols and Oxisols of low pH (3.5-4.2), occurring in high-rainfall areas in southern and western Ethiopia. The pH values for the three major chickpea-producing regions are >5.5, except for Gojam where 65% of the soils tested had pH <5.5 (Murphy 1968).

Frost

Chickpea grown in the intermountain valleys and the highlands above an altitude of 1900 m is prone to frost damage. For example, at Alemaya (altitude range 1900-2300 m) chickpea grown in valleys is subject to frost damage every year.

Irrigation

The potential for high chickpea yields under irrigation seems promising, as is evident from the results obtained at Melkassa II Research Station (see Table 5). At Melkawarer Research Station, Awash Valley, chickpea yields of up to 2900 kg ha^{-1} were recorded under irrigation (Geletu Bejiga, personal communication). The effects of irrigation on chickpea yields are amply demonstrated by the high yields of pulses in general, and chickpea in particular, obtained with irrigation in Egypt and Sudan (see Tables 1 and 2).

Table 9. Soil reaction (pH) data for soils occurring in the Awash River Basin irrigation zone (Murphy 1968). Data indicate number of samples in a particular pH range.

Soil pH range	Relative degree of soil reaction	Upper Awash	Middle Awash	Lower Awash
6.6-7.3	Neutral	1	0	1
7.4-7.8	Mildly alkaline	18	1	31
7.9-8.4	Moderately alkaline	10	4	0
8.5-9.0	Strongly alkaline	1	2	0
>9.0	Very strongly alkaline	1	1	0

Prospects for Extending Chickpea Cultivation

This paper highlights the importance of chickpea as a major pulse crop grown in Ethiopia, raised on residual soil moisture in the waterlogged Vertisols of highland areas in the country. With the possibility of obtaining improved high-yielding chickpea genotypes with greater tolerance of waterlogging, frost damage, soil acidity, soil alkalinity and salinity, soil moisture deficit, and other edaphic stresses, the prospects for extending chickpea cultivation to other areas in Ethiopia seem promising. The reasonable chickpea yields obtained on farmers' fields indicate that chickpea can command a much larger proportion of the farmland in Ethiopia, provided genotypes tolerant to various physical stresses are bred. With the advent of large irrigation schemes in the river valleys and lowlands of the country, prospects seem good for extending chickpea production to these areas, using minimum irrigation water.

Future Research Directions

With changing climatic conditions in the Sahelian zone of Africa, including parts of Ethiopia, the need for selecting drought-tolerant and high-yielding food crop varieties is increasing. Because chickpea is one of the few pulses that grow well under drought conditions, it deserves high priority. The chickpea breeding program in Ethiopia emphasizes selection of high-yielding varieties suited to the various environmental conditions prevailing in the region.

Intensive research is necessary to establish nutrient requirements of chickpea and to identify genotypes tolerant to moisture deficits, soil acidity, soil alkalinity and salinity, waterlogging, and frost damage. To meet the anticipated expansion of chickpea production in Ethiopia, research data on all aspects of chickpea cultivation are needed to formulate an optimum package of practices that can be given to farmers.

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Recommendations

Recommendations

General discussions were held after each session of presented papers. In the final sessions, group discussions were held on (1) climate and drought, coordinated by F.R. Bidinger and reported by R.C. Nageswara Rao, and (2) waterlogging and soil toxicities, coordinated by K.A. Smith and M.C. Saxena and reported by V.M. Ramraj. In the closing session, chaired by J.S. Kanwar and reported by M. Natarajan, the coordinators presented their reports on recommendations for future research, and C. Johansen presented a synthesis of the deliberations.

Following is a summary of the recommendations that evolved.

Climate and Drought

Temperature and Photoperiod

Effects on Phenology

1. To improve adaptation of crops to specific environments, it is vital to understand the environmental factors that control flowering. The paper by Summerfield, Roberts, and Hadley has simplified our understanding by showing that in chickpea flowering is controlled by the additive effects of temperature and photoperiod. This conclusion is based on a limited data set, however, with no accounting for other environmental factors that could affect flowering, such as water and mineral nutrition. The relevance to chickpea improvement of the large amount of temperature and photoperiod data generated by researchers at the University of Reading should be further evaluated.
2. There are only a few studies on temperature and photoperiod effects on pigeonpea, mainly done at the Division of Scientific and Industrial Research, New Zealand. It is urgent that existing data be thoroughly evaluated and that additional controlled environment studies be done.
3. ICRISAT should maintain and expand contact with external laboratories and institutes that have suitable controlled-environment facilities for the study of temperature and photoperiod effects on chickpea and pigeonpea. Guided by their field experience, ICRISAT researchers should participate more directly than previously in framing the research questions to be addressed and designing the experiments to be conducted.

Growth and Grain Yield

1. Screening for low-temperature stress during the vegetative growth phase in winter-sown chickpea should continue at ICARDA, and ICRISAT should concentrate on studying the effects of low temperature on reproductive growth. ICARDA and ICRISAT should collaborate closely in studying low-temperature effects.
2. High-temperature stress poses a definite limitation to chickpea adaptation. ICRISAT should take the lead in studying the deleterious effects of temperatures >30°C on chickpea nodulation, vegetative growth, and reproductive development.
3. Effects of low temperatures on reproductive development need to be defined in pigeonpea, particularly for medium- and long-duration types but also for late-sown short-duration types, and more tolerant genotypes need to be identified.
4. The temperature response curves for growth of both chickpea and pigeonpea need to be better defined, by conducting more controlled-environment studies. At present we have only a limited number of points on the temperature response curve.

Drought Environments

1. It is urgent that agroclimatologists work closely with physiologists and agronomists to classify soil and climatic environments for chickpea and pigeonpea so that agronomic and breeding programs can be properly planned and executed.
2. Because in most areas of the semi-arid tropics the amount of available soil moisture primarily determines crop growth and productivity, a high priority objective is to quantify the available soil moisture for various chickpea- and pigeonpea-growing environments. This parameter should be relatively easy to define for crops grown primar-

ily on stored soil moisture, such as chickpea or postrainy-season pigeonpea, but it is difficult to define for crops grown during the rainy season. Thus, it is necessary to establish relationships between water availability and crop growth and yield. Existing data on this topic should be thoroughly reviewed before further data are generated. Simple simulation models could then be developed, requiring the input of commonly available parameters such as time of sowing, phenology, soil depth, water-holding capacity, rainfall, and irrigation, if applicable. This work requires the concerted input of agroclimatologists, again in close collaboration with physiologists and agronomists, and should be undertaken immediately.

Agronomic Management of Drought

1. Poor plant stand, caused by inadequate soil moisture at seedling establishment, is a major contributor to low rainfed yields of chickpea and pigeonpea. Further studies are needed to define optimum sowing techniques for situations where soil moisture is suboptimal.
2. The principles determining optimum plant population of crops in moisture-deficit environments must be understood to resolve the conflict between optimizing photosynthesis (favored by dense populations) and optimizing water use (favored by sparse populations).
3. Work should continue on evolving cropping systems that best exploit limited amounts of available soil moisture.
4. Further understanding is needed of how various agronomic factors, such as fertilizer use or tillage techniques, interact with water deficit.
5. The question of reflectants and antitranspirants reducing drought stress remains controversial and should receive low priority at ICRISAT.

Genetic Improvement of Crop Adaptation to Drought

Detection of Tolerant Genotypes

1. The growth phases of chickpea and pigeonpea normally subjected to drought stress, and those most sensitive to it, need to be better defined.
2. Drought-screening methods developed for other crops need to be tested for their applicability to chickpea and pigeonpea. Appropriate field experiment designs to handle large numbers of genotypes need to be worked out. As diverse a range of germplasm as possible should be screened.
3. Attempts should be made to identify particular mechanisms evolved by chickpea and pigeonpea to cope with drought stress, within the broad categories of escape, avoidance, and tolerance. Knowledge of mechanisms may help streamline the screening procedure, but undue emphasis need not be given to isolating specific mechanisms of drought resistance in these crops.
4. A better understanding of the root systems of both crops is particularly needed, as this would improve appreciation of how they use limited amounts of soil moisture. Both field and glasshouse studies were recommended. It would be particularly useful to screen for rapid early root growth. Efficient means of measuring root development in the field need to be developed for chickpea and pigeonpea. This presents a particular problem because the crops exhibit extensive rooting behavior. Herbicide placement techniques may be appropriate.

Breeding Procedures to Enhance Resistance

1. Plant breeders need both a clear demonstration of the value of a trait, such as drought tolerance, and a precise screening ability for it, before they are willing to breed for specific traits. Thus, specific breeding programs for drought resistance in chickpea and pigeonpea are not likely to be undertaken until more definitive information is obtained on genotypic differences and on screening techniques suitable for segregating populations.
2. There was no clear consensus on whether breeding simply for increased yield potential of chickpea and pigeonpea would also result in better performance in drought environments. The need to test the performance of traditional and improved genotypes across a range of drought environments, to obtain relative responses to moisture deficits, was suggested.
3. It was suggested that ICRISAT and ICARDA should supply to different locations early-generation bulks of chickpea, which have both high yield potential and a degree of adaptation to drought environments. Selections could then be made for specific local adaptation.

Waterlogging

1. The magnitude of crop losses caused by waterlogging needs to be urgently defined, particularly for pigeonpea, where losses are suspected to be considerable. This will determine research priorities in this area.
2. The causal mechanism of waterlogging damage in pigeonpea needs to be determined to help establish appropriate screening procedures for waterlogging tolerance. Collaboration between ICRISAT and centers of basic research (e.g., universities) should be pursued for this purpose.
3. In screening for waterlogging tolerance, the pot-submergence technique seems to be most useful at this stage.
4. Management techniques to alleviate waterlogging damage, such as planting on ridges, are already well known; further studies are required to refine these management options for different soil types and expected rainfall intensities.
5. Agronomic management options for enhancing crop recovery after waterlogging, such as intercultivation to improve aeration or nutrient application, should be more adequately explored.
6. The deleterious effects of waterlogging on symbiotic nitrogen fixation should be further examined to determine whether the host plant itself or the symbiosis is primarily affected by waterlogging. In addition, *Rhizobium* survival in waterlogged soils needs more detailed examination to determine whether adequate renodulation can occur after the waterlogging is removed.

Soil Toxicities

Salinity

1. It was generally recognized that poor management of agricultural lands often causes salinization and that engineering or management options are the only real solution in many areas. However, the prohibitive costs of these options suggest a scope for improving genetic tolerance to salinity, even in relatively salt-sensitive crops such as chickpea and pigeonpea.
2. The Pulse Agronomy subprogram at ICRISAT should concentrate on genotypic improvement of salt tolerance in chickpea and pigeonpea and leave management aspects to others, such as national organizations.
3. The components of salinity and alkalinity in the soils where ICRISAT conducts trials, as well as in salt-affected areas where chickpea or pigeonpea are likely to be grown, should be better defined to allow for better extrapolation of salinity responses between sites.
4. Attempts should be made to identify salt-tolerance mechanisms available to chickpea or pigeonpea to assist in the screening process.

Soil pH Extremes

1. In the Indian subcontinent, chickpea and pigeonpea are usually grown on neutral to alkaline soils. As most research on these crops has also been done in this region, relatively little is known about their adaptation to acid soil conditions. Such knowledge is important if the adaptation of these crops is to be extended to other regions. For example, many tropical regions where pigeonpea is climatically well suited have acid soil problems. ICRISAT should encourage other research centers to study adaptation of these crops to acid soil conditions and ensure that adequate information is obtained.
2. Further knowledge is also needed on the specific factors limiting growth of chickpea and pigeonpea on soils of high pH. An obvious manifestation on such soils is induced iron deficiency. Other problems, such as the effect of an alkaline medium itself or other induced micronutrient deficiencies, are not always apparent. More detailed information on the nature of the chemical factors involved is needed to evolve suitable alleviatory measures.

Mineral Nutrition

Although not proposed as a topic for this workshop, the question of mineral nutrition, particularly its interaction with the other stress factors discussed, arose quite frequently. The following general recommendations concerning mineral nutrition emerged.

1. A better definition is needed of the nutrient deficiencies most likely to limit the yield of chickpea and pigeonpea on the major soil types on which they are grown. Well-established experimental methods for doing this already exist, including plant and soil chemical analysis and plant growth tests, but they need to be specifically adapted for chickpea and pigeonpea.
2. There were conflicting opinions about the

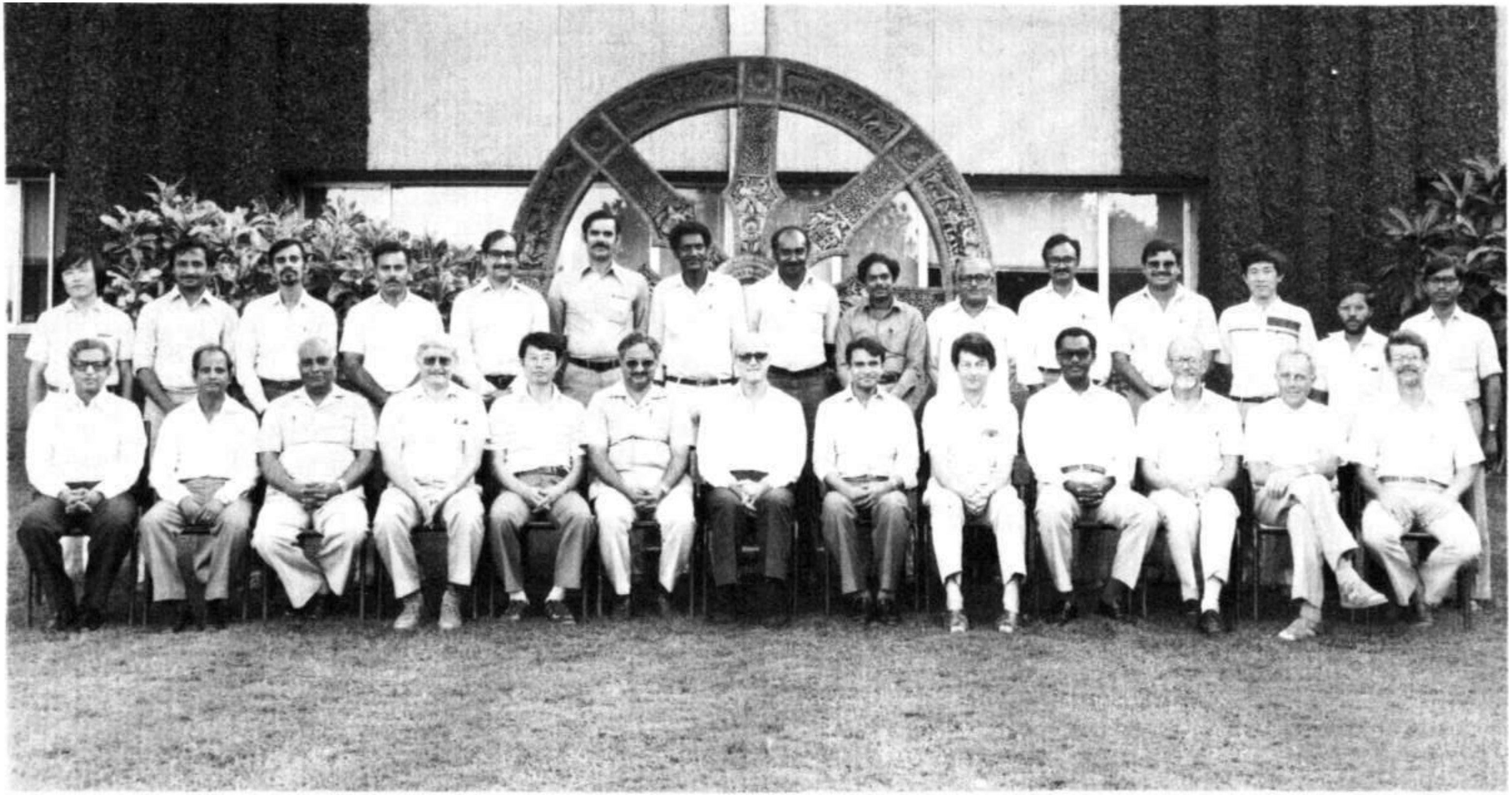
responsiveness of chickpea and pigeonpea to phosphorus application on Indian soils, although these crops generally appeared to be less responsive than cereal crops. A review of the literature on phosphorus responsiveness of chickpea and pigeonpea is recommended.

3. There is a particular need to understand the interaction between phosphorus nutrition and soil-water status for these crops.
4. Investigations should be made to find out whether chickpea and pigeonpea possess any special mechanisms of phosphorus extraction, and if so, whether they can be enhanced.
5. Soil chemical tests of phosphorus availability currently in use, particularly bicarbonate extractions, may not be applicable to such crops as chickpea, which can strongly acidify the rhizosphere.
6. The preliminary work on mycorrhizal effects on the phosphorus nutrition of chickpea and pigeonpea done at ICRISAT should be extended to determine whether plant growth and phosphorus nutrition can be enhanced by mycorrhizal manipulation at the field level.

General Considerations

1. For both established and potential regions for growing chickpea and pigeonpea, careful assessment is required of the relative extent to which the various abiotic stress factors reduce yield from potential levels. This will help establish research priorities. Appropriate experimental procedures to do this, such as factorial studies, need to be developed.
2. Careful assessment is required of whether genetic improvement or agronomic manipulation can best overcome abiotic constraints. ICRISAT and ICARDA have a comparative advantage in genetic improvement research because of their access to genetic resources.
3. When any particular abiotic factor is being studied, it is important to remain aware of the interactions of that factor with other limiting factors.
4. In dealing with these legume crops, it must be determined whether the symbiosis or the host plant itself is most sensitive to particular abiotic stress factors. This knowledge is vital for establishing appropriate screening techniques. For example, if the symbiosis is more sensitive to stress than the host plant itself, then symbioses should be screened.
5. ICRISAT and ICARDA should play a more active role in assessing research priorites for alleviation of abiotic stresses in chickpea and pigeonpea on a worldwide basis. They should identify research organizations best able to tackle the major problems and encourage them to undertake collaborative studies.

Participants



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