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 (Swindale and 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-

1. Legumes Program, ICRISAT.

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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 × 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 the 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 × 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; Schönherr 1976), specific selection for drought environments seems necessary. In crops where G × 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 semi-arid 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.

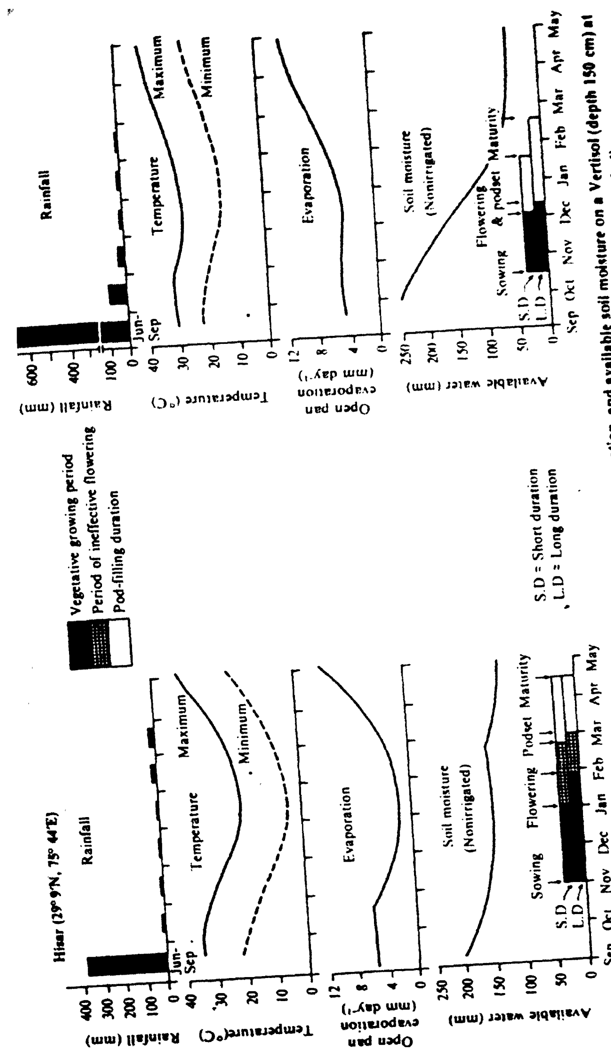

Figure 1. Variation with time in rainfall, atmospheric temperature, open-pan evaporation, and available soil moisture on a Vertisol (depth 150 cm) at Patancheru, near Hyderabad and on an Entisol (depth 100 cm) at Hisar, Haryana during the chickpea-flowering season in India.

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.

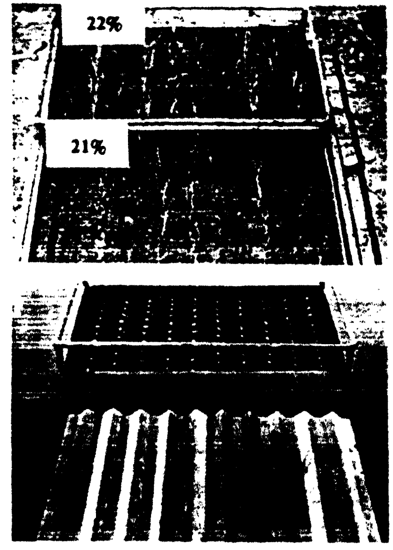

Figure 2. Method of placing seeds in germination trays (bottom) and genotypic differences in emergence at 21% and 22% soil moisture content (top).

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

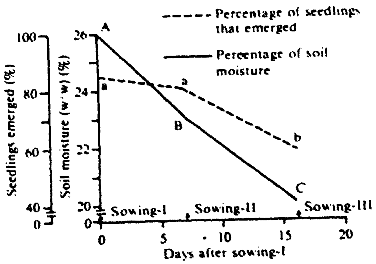

Figure 3. Decrease with time in soil moisture content (w/w) in the top 0-10 cm soil depth, and in percentage of seedlings that emerged.

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

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.

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 wit profile water-holding capacity of about 150 mm nonstress treatments, irrigation at 10-day interv was required to maintain the plots around fi capacity. Receding soil moisture treatments w created by withholding irrigation soon after s flowering. The severity of stress can be altered in method by withholding water either early or lat the season. This method permitted applicatio reproducible stress treatments from year to

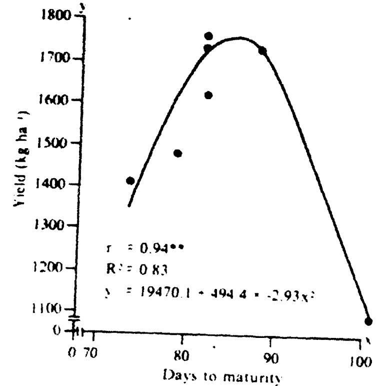

Figure 4. Relationship between growth duration (days to maturity) and yield (mean of three plant densities) in eight cultivars of chickpea grown on a nonirrigated Vertisol.

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:

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

and

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

where

Yo = stress yield,
$\hat{Y}o$ = regression estimate of stress yield,
Y_I = 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_I) and days to flowering (F). The variation (residuals) in stress yields (Yo) not accounted by yield potential (Y_I) 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

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

Characters	Genotypes 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

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.

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.

Maturity group	Days to flowering	R^2	Calculated t values of regression coefficient: Days to flowering	Irrigated yield	Mean seed yield (kg ha^{-1}): 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

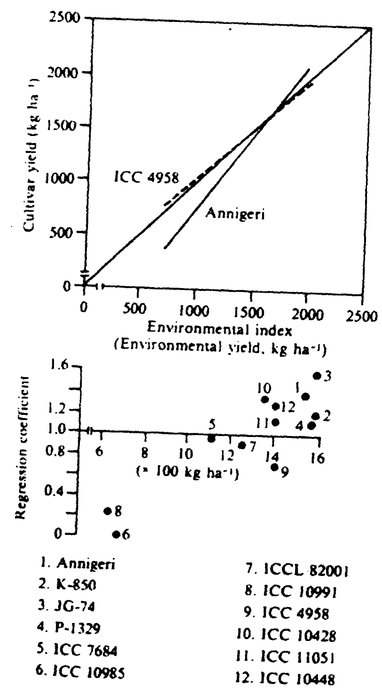

Figure 5. Stability of chickpea yield in stress environments. Diagonal line (top) indicates 1:1 slope.

drought tolerance in chickpea is outlined in Figures 6 and 7.

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 × 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).

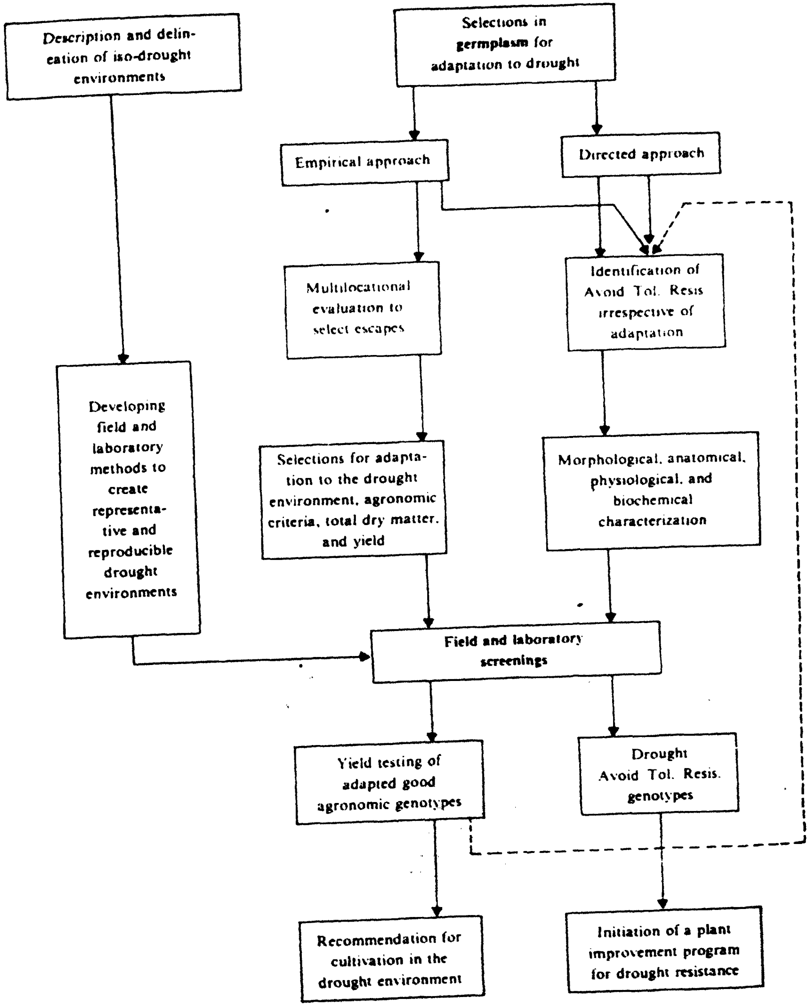

Figure 6. Suggested procedure for identifying drought-tolerant chickpea genotypes.

In India, although most [illegible] 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.

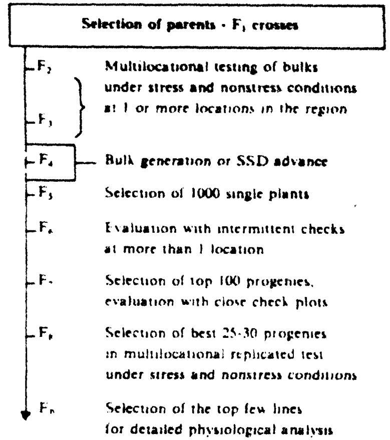

Figure 7. Outline of steps for a breeding program (Sharma and Saxena 1979).

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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