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 1

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 40 000 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 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

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

State	Soils		Cultivated areas[3]	
	Saline[1]	Waterlogged[2]	Pigeonpea	Chickpea
Uttar Pradesh	1295	810	516	1591
Gujarat	1214	464	228	88
West Bengal	850	1850	27	65
Rajasthan	726	348	31	1917
Punjab	686	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)

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 (ICRISAT 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 (Paliwal and 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 mmhos cm^{-1} but cultivar differences were detected at both growth stages A few cultivars were tolerant of salinity up t 9 mmhos cm^{-1} Some cultivars, which showed les tolerance at the germination stage, appeared mor tolerant at the seedling stage, and vice versa Germi nation and seedling growth may be good parameter 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 ho 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 o pigeonpea for salinity tolerance in pots using yield criteria Some workers also used biochemica 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 cultivars 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

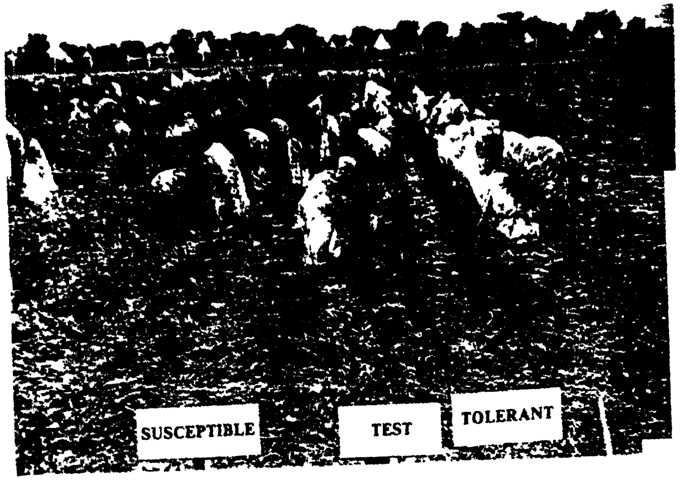

Figure 1. Screening for salinity tolerance in the field. Pigeonpea cultivars C 11 (tolerant) and (susceptible) have been planted on either side of the test row.

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 atisfactory in determining the relative tolerance of est cultivars even under such heterogeneous soil alinity conditions (Fig 1) The test lines were scored elative to adjacent tolerant and susceptible controls or survival at different stages of growth Good differential responses were usually observed in moder ely saline areas (about 6 mmhos cm^{-1} ESE) with uch lower rates of survival in the susceptible con ol rows than in the tolerant rows Genotypes sur ing either better than or equal to tolerant controls re classified as tolerant A number of advanced eding lines and cultivars that survived better than tolerant control, cv C 11, were identified using s method (Fig 2)

This method could be improved further if a natu- or artificially created gradient of salinity were ilable in the field The genotypes could be nted along the gradient, and the length of surviv- row could be treated as an index of the geno- 's tolerance

ening in brick chambers To test the perfor- ce of genotypes under more controlled condi- , a series of brick chambers (1 × 1 × 1 5 m) were tructed, with drainage taps at the base The bers were filled with black soil artificially salin- with various levels of a mixture of NaCl, Na_2SO_4 $CaCl_2$ (7 1 2) At lower salt levels (40 milliequi- ts kg^{-1} soil), clearcut differential responses en cultivars were observed Genotypes C 11 CP 3786 showed tolerance and JA 275 and HY owed 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-

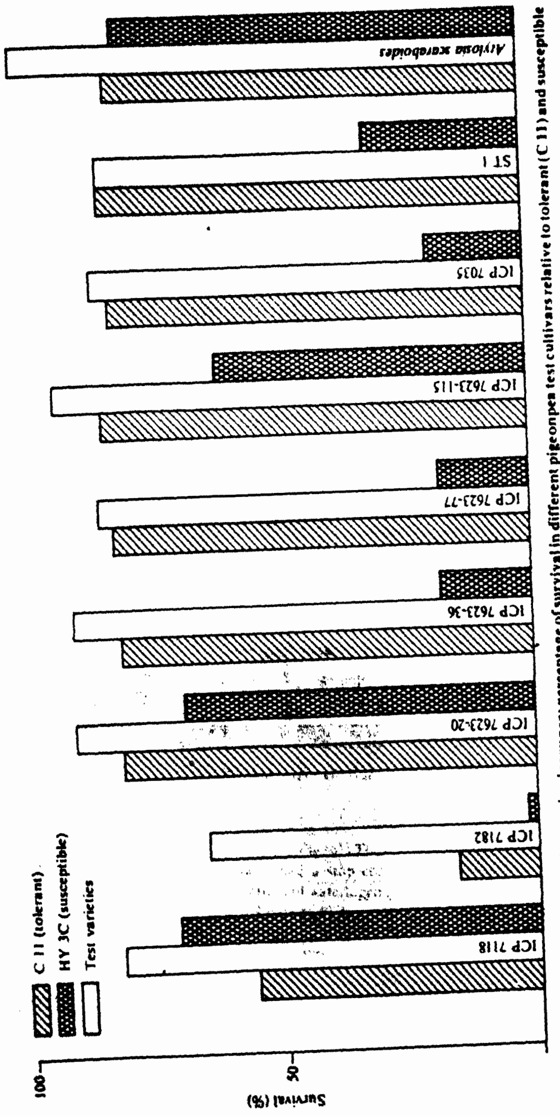

Figure 2. Screening for salinity tolerance in pigeonpea: percentage of survival in different pigeonpea test cultivars relative to tolerant (C 11) and susceptible (HY 3C) controls.

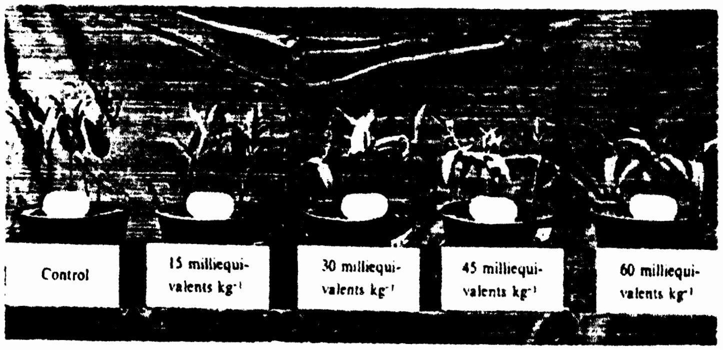

Figure 3. Effect of different levels of salinity on tolerant pigeonpea cultivar C 11.

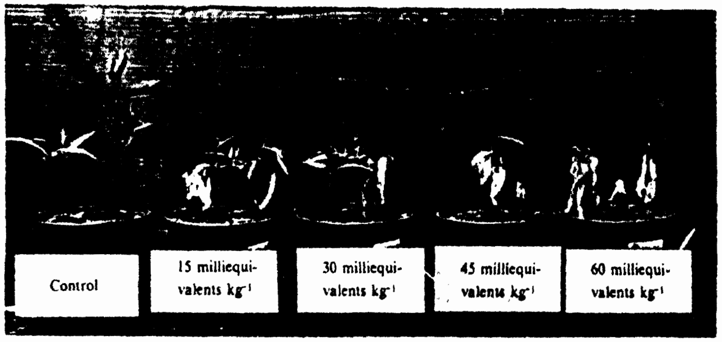

Figure 4. Effect of different levels of salinity on susceptible pigeonpea cultivar HY 3C.

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

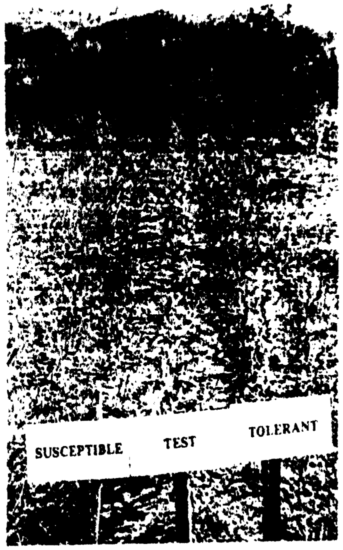

Figure 5. Screening for waterlogging tolerance in the field. Pigeonpea cultivars BDN 1 (tolerant) and HY 3C (susceptible) have been planted on either side of test rows.

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

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.

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.

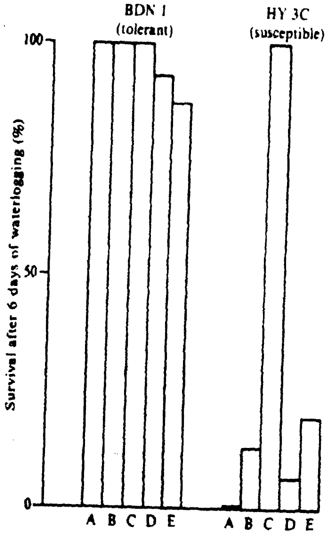

Figure 7. Percentage of survival after waterlogging of two pigeonpea cultivars (BDN 1 and HY 3C) in Vertisols collected from different fields at ICRISAT Center.

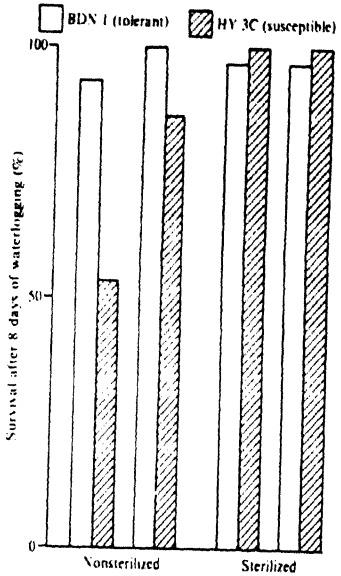

Figure 8. Percentage of survival of two pigeonpea cultivars (BDN 1 and HY 3C) in sterilized and nonsterilized Vertisols in pots at ICRISAT Center. Soil samples were collected from two spots, and results of each are presented separately.

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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