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Environmental Influences on Root Morphology and Development of Desi and Kabuli Chickpea (Cicer arietinum L.)

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ENVIRONMENTAL INFLUENCES ON ROOT MORPHOLOGY AND DEVELOPMENT OF DESI AND KABULI CHICKPEA (CICER ARIETINUM L.)

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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INTRODUCTION

Chickpea (Cicer arietinum L.) is one of the most cultivated legumes in the world. They are grown in Asia, to some extent in Southern Europe, and in parts of North Africa (Ladizinsky and Adler 1976; Smithson 1985). Chickpeas are categorized into two major types, Desi and Kabuli, also known as Gram and Garbanzo. The two types are primarily distinguished by seed type (color and shape). Desi types have small, sharp-edged seeds with rough coats,and colors ranging from light brown to black and pink flowers. Kabuli types have medium to large seeds with smooth thin coats, and cream to white seed color and white flowers. Desi are regarded as the primitive types from which the Kabuli types developed through mutation and selection for light-colored seeds and white flowers (Moreno and Cubero 1978).The wild ancestor of all cultivated chickpeas is thought to be Cicer reticulatum (Ladizinsky and Adler 1976).

Desi types display superior emergence compared to Kabuli types under field conditions and this is thought to be associated with seedling vigor (Saxena 1979). Generally Desi types are considered to be efficient producers, but these claims have not been substantiated by research findings. Desi chickpeas were found to be less susceptible to the pod borer (Heliothus armigera) and also have higher crude fiber and lower fat content in the grain than Kabuli types (ICRISAT 1976/77).

LITERATURE REVIEW

Root Morphology and Plant Response to the Environment

Chickpeas have a distinctive taproot (primary root), adventitious roots (arising from stem tissue), and lateral or secondary roots (arising from the taproot). A distinctive taproot is a result of the postponement of secondary root formation (MacKey 1980a).

According to MacKey (1980a), the root system pattern is determined by the functional asymmetry of the taproot versus the number and position of secondary and higher order roots. If taproot branching occurs early in plant development then secondary roots may compete with the taproot restricting further taproot branching and leading to downward growth of the taproot. This relationship influences the depth and width of the root system.

Root systems are important for the absorption of water and nutrients, anchorage of the plant in the soil, carbohydrate storage, and production of growth metabolites (Dodd 1962; Kolesnikov 1971). Generally the environment plays a major role in the proliferation of the root system.

The efficiency of soil exploitation depends on the spatial distribution of the root system and the ability for increased growth in those parts of the root system which are exposed to favourable

conditions. Bowen (1970) found that the most important factors for phosphate uptake from the soil were root elongation, production of new growth, and extent of root hair production. Russell (1977) suggested that the major parts of the root system contributing to nutrition of plants are length, surface area, and volume or weight. Root hairs and adventitous roots contribute to a greater surface area and play a role in the absorption of water and nutrients. Increased root surface area has been implicated as a mechanism of providing water to the plant under stress conditions (Sharma et al. 1977). MacKey (1980a), indicated that a shallow root system may be advantageous where light rains are experienced. A large root biomass (Aycock and McKee 1975; Stofella et al. 1979) and spreading angle (Pinthus 1967) have been suggested as playing major roles in reducing lodging. A large taproot and hypocotyl diameter may provide a stronger root system and better anchorage (Stofella et al. 1979).

The presence of Indole Acetic Acid has been established in maize (Zea mays L.) roots (Bridges et al. 1973; Elliott and Greenwood 1974). Short and Torrey (1972) demonstrated the occurrence of cytokinins in pea roots. Restriction of the root system in beans (Phaseolus vulgaris L.) resulted in reduced plant growth, which could be restored by application of gibberellins (Carmi and Heuer 1981). This was thought to be indicative of the root system as a site of hormonal production essential for shoot growth.

Genotypic Variation and Root Morphology

Genotypic variation has been observed for root morphology and distribution patterns within several plant species. Many of these studies have been conducted relatively recently and include soybeans (Bohm et al. 1977; Garay and Wilhelm 1983; Kaspar et al. 1978 and 1984; Raper and Barber 1970; Sivakumar et al. 1977; and Mitchell and Russell 1971), wheat (O'Brien 1979), tomatoes (Stofella 1983), sorghum (Nour and Weibel 1978; Wright et al. 1983; Jordan et al. 1979), black beans (Stofella et al. 1979), alfalfa (Pederson et al. 1984), peanut (Ketring 1984), oats (Barbour and Murphy 1984), and chickpea (Nagarajrao et al. 1980).

Root morphology is difficult to relate to other plant characteristics but a few studies covering a range of crops have attempted to establish relationships between root morphology and plant growth. Results of studies on black drybeans suggest root biomass to be an important component of lodging resistance (Stofella et al. 1979). High root weight, biological yield, uprooting resistance, and less lodging were implicated as indicative of high seed yield. Other correlations established were between taproot weight and diameter, as well as stem diameter. In green gram (Vigna radiata) seedling root numbers, root length, fresh shoot weight, and dry root weight were all found to be correlated to seed yield between genotypes (Rangasamy and Shanmugan 1985). High grain yield, seed number, and plant height in nonstressed oat seedlings were found to be associated with high root length (Barbour and Murphy 1984).

Differences in root morphology (taproot length and growth rate, number of lateral roots, and root weight) have been observed within soybean cultivars (Raper and Barber 1970; Kaspar et al. 1978). Kaspar et al. (1978) reported variability between cultivars for root elongation during various stages of reproduction. Clear differences in the root distribution and surface area of soybean varieties grown as single plants were demonstrated by Raper and Barber (1970). The highest concentration of primary lateral roots was found in the top 0.15 m of soil. Below this layer the taproot reduced to the same diameter as primary laterals with very little branching. Similar observations by Mitchell and Russell (1971) led to the conclusion that root behaviour within the top 0.15 m of the soil surface is characteristic of the root morphology of soybean. Kaspar et al. (1984) suggested that the rate of taproot elongation was related to root depth in soybean.A slow rate of elongation was associated with less roots in the soil profile.

Mitchell and Russell (1971) suggested that root growth of soybean occurs in three stages; vegetative top growth which is accompanied by downward taproot and shallow horizontal lateral root development; flowering and pod formation which accompanies root development to 0.76 m depth, and seed maturity which comes at the time of lateral root penetration deeper into the soil profile.

Heterosis was found for length of seminal root, growth rate of adventitious roots, and root volume in sorghum (Blum et al. 1977). The larger root volume was thought to be a result of increased root numbers and growth of lateral branches. This seems to agree with the finding

by Jordan et al. (1979) which suggested that there is sufficient variability in sorghum to warrant further research for improvement of sorghum root systems which may allow superior crop performance in specific enviroments.

Variability for taproot length and number of laterals was observed in cotton; as well as correlations with shoot growth (Quisenberry et al. 1981). Root morphological differences among tomato cultivars were shown to be restricted to basal root weight (Stofella 1983). Genetic variability for root characteristics in alfalfa were in lateral root numbers, and root diameter (Kaspar et al. 1984). Ketring (1984) demonstrated variability for root volume in peanut.

Root distribution was shown to differ among chickpea varieties under field conditions (Nagarajrao et al. 1980); but a relationship between root morphology and moisture depletion was not always evident. The quantity of chickpea roots decreased considerably with depth and beyond 0.45 m the quantity was not appreciable. However, variability in root weight and distribution near the soil surface existed between varieties. The variety which exhibited the lowest root mass in the upper portion of the soil profile had more active nodules, a sign of root efficiency. No mention was made of different chickpea types. Genotypic differences in chickpea root behaviour for vertical and horizontal branching of roots was cited by Minchin et al. 1980. Singh et al. (1980), reported that root dry weights of chickpea decrease with depth.

Environmental Effects on Root Morphology

Plant breeding selection criteria are usually based on shoot and other above ground characteristics, and not root characteristics. MacKey (1980a) is of the opinion that in the early stages of plant growth the genetic pattern of root development is already decided; whatever happens thereafter is the effect of the environment. Each species and genotype has a different genetic pattern which responds differently to environmental stresses. It is the ability for a certain genetic framework to successfully adjust to prevailing environmental conditions that is of interest during most of the growing season.

Chickpea root weights and reproductive growth have been shown to increase with photoperiod. Economic yield of chickpea seems to depend on the rate of root senescence which in turn is influenced by temperature and shows variability among varieties (Minchin et al. 1980). They suggested that rapid root senescence during seed filling restricts the ability of the plant to exploit additional soil volume and may result in lower yields. Physical properties of the soil are implicated in plant root growth. Malik et al. (1985) demonstrated an increase in root growth of chickpea with increasing clod size.

Stofella (1981) reported a positive effect of increased row spacing on total root weight, shoot weight, and stem and hypocotyl diameters of kidney beans. Volume of the root media may affect plant growth. Carmi and Heuer (1981) showed that a limited root system restricts shoot growth. They suggested a hormonal mechanism involving

gibberellins or cytokinins.

Root morphology differs between plants grown as single plants and rows (Raper and Barber 1970). Primary branches of single plants tend to leave the taproot at much greater angles and continue downward through the soil with fairly constant slopes. In row plots primary branches spread outward and continue toward the center of the row for varying length before angling sharply downwards.

Knowledge of variation in root traits in response to enviromental conditions is necessary for use in crop improvement. Some environmental factors restricting root growth and function in the soil are discussed in the following sections.

Salinity:

Most of the world's non-arable lands are affected by natural salinity; in addition to these there are soils which became saline through irrigation waters and fertilizer application. The ability of plants to survive under such conditions primarily depends on the success or failure of roots to proliferate. High sodium chloride concentrations generally reduced germination of chickpea varieties (Kheradnam and Ghorashy 1973; Kumar et al. 1980). Munchanda and Sharma (1980) observed increased pod and grain numbers in chickpea plants grown under saline conditions (almost twice that of the control). They suggested that the reduced vegetative growth under saline conditions could have resulted in a developmental shift. Reduced seed size, protein content and 100 seed weight (about 37% less than control) were

observed under saline conditions (Kumar et al. 1980). Salinity caused a delay in the germination of chickpea (Jaiwal et al. 1983). Shoot and root lengths decreased with increasing salinity and shoots were more affected than roots. Development of lateral roots was depressed and the effect was thought to be related to water stress. The effects of alkalinity and salinity on chickpea were reported as delayed emergence, poor plant growth, and mortality under field conditions (Singh and Singh 1984). They also observed varietal differences in response to these stresses.

Variability for response to salinity has been observed among and within species. Devitt et al. (1984), working with sorghum and wheat, demonstrated differences between these species in response to saline conditions. Root dry matter and elongation decreased as Na concentration increased in sorghum; whereas in wheat, root elongation increased as Na concentration increased. Francois et al. (1984) explained yield reduction of sorghum under saline conditions as a result of lower weight per head. They also noted that sorghum was more salt tolerant at germination than at any other growth stage. Although large environment x genotype interactions make breeding difficult, tolerance of NaCl during germination has been shown to be a highly heritable trait in alfalfa (Allen et al. 1985). Most studies on salinity have been at the seed germination stage which may not reflect what will happen at later stages. However, since germination involves ability of the radicle and shoot to emerge and elongate, it should provide critical information about the limitations that salinity impose on plant growth. In chickpea,

responses ranged from poor emergence to delayed emergence, with some good stands and plant growth obtained (Kheradnam and Ghorashy 1973).

Moisture Stress:

Generally the environment plays a major role in the proliferation of the root system. When water and nutrients are abundant the root system will not be extensive in growth; the opposite is true when water and nutrient supplies are limited (MacKey 1980b). In cases where available water is located deeper in the soil profile, the root system will be deep and more dry matter will be allocated to the roots. Both horizontal and vertical parts of the root system have important roles to play in variable climates.

Root characteristics have often been implicated as playing a major role in drought resistance of several crops (Nour and Weibel 1978; Hurd 1968). The capacity of the root system to provide the necessary moisture to the plant depends on the root surface, its efficiency, spatial distribution in the soil and fibrousness (MacKey,1980b). The optimal size for a desirable or efficient root system under conditions of moisture stress is unknown and a matter of controversy. Passiouri et al. (1972) suggested that small-rooted plants may use water more efficiently under conditions of limited water availability; the alternative which is held by most authors is that extensive root systems can explore more soil volume and therefore transport more water to the plant (Garay and Wilhem 1983; Salim et al. 1965). Shallow roots have been considered a possible advantage where

light rains are experienced (MacKey 1980a).

Garay and Wilhelm (1983) demonstrated that under drought conditions, root density varies with moisture depth, i.e. low at the dry surface layer of the soil and much higher at deeper moist layers. The implication is that root proliferation follows moisture paths. Well watered plants of maize exhibited greater lengths at upper soil levels whereas in drought stressed plants, roots penetrated deeper into the soil profile and were less dense at surface levels (Sharp and Davies 1985). Also soil moisture depletion rates for unwatered plants were higher per unit root length as compared to well-watered plants.

Salim et al. (1965) found that drought tolerant varieties of wheat, oat and barley possessed longer roots and had a higher root density in the soil profile. Variability was shown to exist for root characteristics within species. Hurd (1968) demonstrated variability in the rate of root penetration into dry soil and more growth in wet soil layers. Depth of irrigation was found to affect rooting pattern of alfalfa. Jodari et al. (1983) found that non-irrigated plants produced extensive root systems compared to their irrigated counterparts, i.e. had greater length.

Sharma and Ghildayal (1977) indicated that under moisture stress roots become longer and finer, thus implicating increased surface area as the mechanism of providing water to the plant.

High irrigation frequency promoted development of a shallower root system in wheat as compared to low frequency irrigation (Proffitt

et al. 1985). The explanation given was that dry conditions at the upper layers of low frequency irrigation induced plants to explore favourable conditions at deeper levels. The important factor seems to be high root lengths in wet regions of the profile. Plants with roots that growvigorously tend to follow the receeding water table if the growing season begins with a full soil profile. The traits which seem to be associated with these are; root size, diameter, length, and branching. McIntosh and Miller (1981) demonstrated that root branching of alfalfa is limited by moisture stress, and concluded that soil moisture influences the expression of the branching trait in alfalfa.

When water is readily available the plant's increased demand for water can be met by an increase in root density or increase in absorption efficiency per unit of root length (Reicosky et al. 1972). In soybean, maximum root depth corresponds with depth of maximum water uptake; in contrast corn showed root depths which were 0.15-0.30 m beyond the water uptake sink (Allmaras et al. 1975). The greatest soil water depletion was found at greater depths of root distribution pattern in soybean (Stone et al. 1976). This was attributed to the fact that roots are younger, less crowded, have more surface area, and are in wetter parts of the soil profile. On the same basis, Taylor and Klepper (1973) concluded that water uptake was greatest at lower root densities, and postulated that roots deep in the profile probably are more effective.

Temperature:

Most root morphology studies do not include temperature as a variable. Stone and Taylor (1983), working with soybean, demonstrated that the rate of taproot elongation increased with temperature and decreased with time at temperatures greater than 17°C. Rate of lateral root extension also increased with temperature and time at temperatures less than 29°C. He suggested the possibility of altering the rate of elongation through temperature manipulation in order to increase root length during drought stress. Variability existed among varieties for rate of elongation in response to temperature.

In cotton it was shown that there was a temperature optima for root and hypocotyl elongation and this optima shifted with time and growth stage (Arndt 1945). Favorable temperature for secondary root development was less favourable for hypocotyl and primary root elongation. Supraoptimal and suboptimal temperatures suppressed secondary root initiation. In blue grana (Bontelona granilis), the largest number of adventitious roots per seedling were initiated at 30°C and 15°C. was the minimum (Briske and Wilson 1977). Temperature is implicated as very important in stand establishment which depends on the rate of root elongation that is sufficient to keep a portion of the root system in moist soil.

MATERIALS AND METHODS

FIELD AND GREENHOUSE EXPERIMENTS TO EXAMINE GENOTYPIC VARIABILITY

Experiment 1: Six Chickpea accessions were used in the study during winter 1983, two from each of Kabuli, Desi, and intermediate types. The following accessions were used:

CULTIVAR	TYPE	SOURCE	SEED COLOR
Icc-5810	Desi	India	Black
X81-th 105	Intermediate	ICARDA	White
IIc-482	Kabuli	Turkey	White
Icc-11524	Desi	ICRISAT	Brown
IIc-1919	Kabuli	India	White
X81th-111	Intermediate	ICARDA	White

The growing mixture was prepared by mixing clay soil, sand and peat in the ratio 2 :1:1(v/v), respectively. Four seeds of each variety were planted 20 mm deep in clay pots 132 mm in diameter and 135 mm deep. After two weeks, seedlings were thinned to two uniform plants/pot. Plants were watered adequately every other day to prevent moisture stress. Temperatures in the greenhouse were maintained at 25°C throughout the growing period and no supplemental lighting was provided. Plants were allowed to grow to flowering after which measurements were taken. Root washing was done by initially soaking the pot in water to soften the soil. The final cleaning was done on a

200mm soil sieve by water directed from a sprinkler head. The whole plant with intact root system was trapped on the screen, and then cut into different parts. Lateral root number, and shoot and root dry weights were recorded. Results were analysed as a completely randomized design with four replications.

Experiment 2: The experiment was conducted at two locations (Highmore and Brookings) during summer 1984, using six chickpea accessions. These were the same accessions as those used in experiment 1. Planting was done by use of a jab planter in hills spaced 0.90 m. apart and seeds placed about 40 mm deep. One row of twenty-seven plants was considered to be a plot in a randomized complete block design with four replications.

Root excavations were done at flowering using a 77 mm diameter tube. Sampling depth was 0.18 m and sample size was five plants per accession per replication unless otherwise stated. Roots were washed by water directed from a sprinkler head and stored at 4°C until all data had been collected. Taproot diameter, lateral root numbers on the top 0.1 m of the taproot, and shoot dry weight were recorded.

Experiment 3: Four accessions were chosen for the 1985 season on the basis of the results of the first experiment (1984). The four accessions (ICC 5810, ILC 482, ICC 11524 and ILC 1919) were planted at Brookings by use of a jab planter in hills 0.6 m apart. Another set was planted in rows 0.60 m apart and 0.1 m within row spacing.

First samples were harvested at flowering using a 77 mm diameter tube. Sampling depth was 0.18 m over the row and sample size was five plants per replication per cultivar for both sets. Samples were soaked overnight in water containing calgon and washed the next day in a Hydropneumatic root washer (Smucker et al., 1982).

Second samples were taken at podding for root length measurements. Sampling was done by means of a 55 mm diameter tube driven into the soil to a depth of 1.20 m. The soil column was divided into 0.1 m sections for measurement of root length at different depths. Sample size was two plants per cultivar per replication. Samples were taken 0.05 m away from the plant stem in order to avoid the taproot. Data collected included number of lateral roots and taproot diameter (not on root length samples) for the top 0.1 m of taproot. Diameter was measured by means of a graduated magnifier. Root length was determined using a modified Newman procedure (Bohm, 1979) of counting the number of intercepts between roots and random straight lines. Shoot weights and yield were also measured.

Environmental Variability

Experiment 1: The experiment was conducted to determine the effect of salinity on germination, root development, and plant growth. Four chickpea lines were used; two from the salt tolerance screening experiment, (ICC 4918 and ILC 134) and two from the greenhouse and field experiments conducted in 1983 (ICC 11524 and ILC 482).

The experiment was conducted in a cooled greenhouse in summer 1985. Temperatures were maintained at 25°C and supplemental lighting was provided by high pressure sodium lamps for 10 hrs each day. Four types of soils and a greenhouse mixture (2:1:1 soil:peat:sand v/v) were used. The soils were: Ryan cultivated, Ryan uncultivated (Fine, Montmorillonitic (calcareous), Frigid Vertic Haploquolls), Ludden cultivated and Ludden uncultivated (Fine, Montmorillonic Frigid Typic Natraquolls). soil testing results for these soils are given in appendix A.

The experiment was conducted in two sets; one set was harvested at flowering for root and shoot measurements and the other set taken through maturity for yield component measurements. Three seeds were sown in a 123 mm diameter x 162 mm deep porcelain pot at a depth of 20 mm. Thinning was done three weeks later to leave two plants in each pot. Pots which did not contain the required number of plants were replanted. Plants were harvested at flowering for measurement of root and shoot dry weights, taproot diameter (measured on fresh samples by means of a graduated magnifier), and lateral root numbers taken on top 0.10 m of the taproot. Pod and seed numbers were taken at maturity. Results were analysed as a completely randomized design with three replications.

Experiment 2: Moisture stress experiment. The same four cultivars used in the above experiment were grown under five moisture treatments in the greenhouse in plastic pots of 160 mm diameter and 130 mm depth. Three seeds were planted in each pot at 20 mm depth. Two

weeks later plants were thinned to one per pot. The mixture used was clay soil: sand: peat in the ratio 2:1:1(v/v), respectively. A moisture characteristic curve for this mixture was developed (Appendix E) by use of a pressure plate. Moisture treatments were as follows: 0.26 g water/g soil, 0.15 g water/g soil, 0.08 g water/g soil,0.06 g water/g soil, and cycles of 0.26 g water/g soil and 0.06 g water/g soil. The above moisture treatments correspond to water potentials of 0, -0.33 bar, -6 bar, -12 bar and a 0/-12 bar cycle respectively.

A known weight of soil was used per pot. For the first two weeks all pots were watered adequately (field capacity) to allow for germination. Then moisture treatments were imposed by weighing pots every day and adding water as dictated by the moisture characteristic curve. This resulted in the development of varying degrees of vertical moisture gradients within the pot. The 0.26 g / 0.06 g cycle treatment was allowed to dry to the same water content (by weight) as the 0.06 g treatment before it was rewatered to the 0.26 g level. Temperatures in the greenhouse were approximately 25°C and no supplemental lighting was provided. Soil samples were taken from each treatment (the entire depth of the pot) and divided into 20 mm sections for moisture profile measurements. A completely randomized design with four replications was used. Plants were harvested 28 days after planting and roots washed on a 200 mm soil sieve with water directed from a hose. Root length, taproot length, number of lateral roots, and taproot diameter for the top 0.10 m of the taproot were recorded.

Experiment 3: An experiment was conducted to determine the

effect of salinity and moisture stress on germination, root development, and growth of chickpea. Twenty four accessions of chickpea were taken at random from the germplasm (appendix B). Three osmoticum were used: sodium chloride, calcium chloride, and mannitol, each prepared to concentrations giving osmotic potentials of 0, -4, -8 and -12 bars as determined by Van't Hoff's equation.

$$\pi = RTn / V$$

R = gas constant

T = temperature

RT = 22.12 liter bar^{1} at 20°C

n = moles of solute.

V = volume of solution.

ii = osmotic potential (-bars).

Water potentials were verified by measurements on a Wescor dewpoint microvoltmeter (HR-33T) and chamber model C-52. Electrical conductivity for all solutions was checked on an Industrial Instruments Conductivity Bridge (model RC).

Germination was done in accordance with recommendation of the Proceedings of the Association of Official Seed Analysts (volume 60 No. 2), except for seed number which was limited by availability. Fifteen seeds of each line were used per treatment. Seeds were surface sterilized in 10% chlorox for 2 minutes and after rinsing several times in distilled water, germinated in paper towels moistened in 20 ml of the relevant solution. Each paper towel was then placed in a plastic bag to minimize evaporation. Incubation was in alternating temperatures of

30°C for 8 hrs and 20°C for 16 hrs in the dark.

First germination counts were taken after 3 days, and every other day thereafter, up to 7 days of incubation. A seedling was considered germinated if it had a radicle of at least 10 mm long. Distilled water was used as control for all solutions. The experimental design was completely randomised with three replications.

In order to monitor the potential for growth under salinity stress, five plants were sampled at random from each treatment per replication for radicle and hypocotyl length measurements at the end of the experiment (7 days). All length measurements were to the nearest ten millimeters.

Cumulative germination was expressed as the percent of the number of seed germinated and controls were also compared to check for inherent varietal differences in germination.

Experiment 4: The experiment was conducted to determine the effect of temperature on root development and growth. Four chickpea genotypes were used: ILC 482, ICC 4918, ICC 11524 and ILC 134. Seeds were surface sterilized in 10% chlorox for 2 minutes, rinsed and germinated on paper towels moistened in distilled water. They were then incubated for 10 days at temperature treatments of 10, 15, 20, 25, 30 and alternating 20 / 30°C. A completely randomized design was used with three replications. Ten healthy plants per genotype per replication were measured for radicle and shoot length, number of lateral roots, number of leaf nodes and diameter of the taproot 50 mm from the seed

position. Lateral root numbers were taken for the entire length of the taproot. Analysis of variance was performed on data to compare root behavior and characteristics of different cultivars.

RESULTS

Root Morphology

Root morphological results indicated highly significant differences among accessions in secondary roots, adventitious roots, and shoot weights, at Brookings (Table 1). The Kabuli types (ILC 482 and ILC 1919) were larger and had a higher root branching density along the taproot. ILC 482 ranked highest in these measurements and the trend was maintained from year to year (Table 2). Taproot diameters did not show significant differences among accessions at Brookings in 1985. There were outstanding differences in shoot weight between 1984 and 1985, with 1985 plants being larger. This could be explained in part by the excessive moisture of 1984 season while the 1985 trials experienced relatively dry weather.

Results from the row planting experiment indicated significant differences among accessions for shoot weight, taproot diameter, and secondary roots (Table 3). The trend was the same, with Kabuli types showing a higher density of root branching as compared to the Desi types. Adventitious roots seemed to vary greatly with environment. Only a few developed under row planting as compared to single plants (Table 2 & 3) ILC 482 still ranked highest in root branching density.

Results for the Highmore experiment are presented in Table 4. Only shoot weights showed significant differences among accessions.

Table 1 : Root Morphology and Shoot Dry Weights of Chickpea Accessions and Types (K = kabuli, D = desi, I = intermediate) at Flowering Stage (single plants) in 1984 at Brookings

Accession	shoot weight	taproot diameter	secondary roots	adventitious root numbers
	(g)	(mm)	(no./m)+	
ILC 482 (K)	7.62	2.7	2030	62
ILC 1919 (K)	6.84	2.8	1600	41
X81 th 105 (I)	7.34	3.0	1820	49
X81 th 111 (I)	7.50	3.1	1750	51
ICC 5810 (D)	5.94	2.7	1540	31
ICC 11524 (D)	8.01	2.6	1350	52
F(prob.)	0.0001	0.05	.0001	0.05

+Top 0.10 m of the taproot.

Table 2 : Root Characteristics and Shoot Dry Weights of Chickpea Accessions at Flowering Stage (single plants) in 1985 at Brookings

Accession	Shoot Weight	taproot diameter	Root branching secondary+	adventitious
	(g)	(mm)	(no./m)	
ILC 482 (K)	27.5a	4.0	1680	64
ILC 1919 (K)	19.7b	4.2	1620	32
ICC 5810 (D)	18.7b	4.2	1350	19
ICC 11524 (D)	18.6b	4.0	1220	49
F(Prob.)	0.001	0.36	0.02	0.0001

+Top 0.10 m of the tap root.
Means with the same letter are not significantly different.

Relative comparisons indicated ILC 482 had a higher root branching density although the differeces were not significant. The plot at Highmore was flooded for sometime after emergence and this may have resultedin low root branching density as compared to the results from Brookings for the same year (Table 1). Under greenhouse conditions plants did not develop adventitious roots, but the trend in root branching density was maintained (Table 5). The results indicated large differences in shoot weight between field and greenhouse experiments. Although the greenhouse experiment was conducted under optimum conditions of moisture and temperature; the growth media was limited by size of the pot. Carmi and Heuer (1981) demonstrated that a limited growth media reduces plant growth. It is interesting to note that in spite of the the large differences in shoot weight between the field and the greenhouse, root branching seemed to be consistent. This may indicate that the pattern of root development is determined early in the season.Root branchingat the top of the taproot had already exhausted its potential for development by the time the size of the root media became limiting. In general the Kabuli types had a higher density of root branching than the Desi types, and this seems to be in accordance with seed size (Appendix D).

As shown in Fig 1 & 2 taproot diameter and root branching density decreased with depth. Approximately 75% of all root branches on the top 0.10 m of the taproot were found in the top 0.06 m. Major differences among accessions in root morphology seemed to be in this region. As depth increased the taproot is reduced in diameter and

Table 3 : Root Characteristics, Seed yield, and Shoot Weight of Chickpea Accessions at Flowering Stage in 1985 at Brookings (rowplanting)

Accessions	shoot weight (g)	seed yield (g)	taproot diameter (mm)	secondary roots (no./m)+	adventitious roots
ILC 482(K)	16.4a	177.2	3.7	1720	8
ILC 1919(K)	12.9b	173.2	3.8	1520	1
ICC 5810(D)	10.5bc	146.0	3.5	1280	6
ICC 11524(D)	7.9c	170.0	4.0	1280	7
F(Prob)	.002		.002	.02	.67

+ Top 0.10 m of the taproot.
Means with the same letter are not significantly different.

Table 4 : Root Characteristics and Shoot Weights of Different Chickpea Accessions at Flowering Stage (single plants) in 1984 at Highmore

Accession	shoot weight	taproot diameter	secondary roots	adventitious root numbers
	(g)	(mm)	(no./m)+	
ILC 482(K)	8.44a	3.24	696	7
ILC 1919(K)	4.37b	2.88	536	22
X81 th105(I)	8.62a	3.36	652	49
X81 th111(I)	10.29a	3.20	630	47
ICC 5810(D)	6.57a	2.98	488	19
ICC 11524(D)	4.50b	2.58	450	40

+Top 0.10 m of the taproot.
Means wth same letter are not significantly different at 0.05 probability (Waller Duncan).

secondary roots along the taproot decreased. Kabuli types, which showed higher root branching density as compared to Desi types, had relatively larger taproot diameters.

Table 5 : Least Square Means for Root and Shoot Dry Weights and Secondary Roots Under Greenhouse Conditions at Flowering in 1984

accession	root weight	shoot weight	shoot/ root	secondary roots
	(g)	(g)	ratio	(no./m)+
ILC 482(K)	0.16	0.36	0.44	1960
ILC 1919(K)	0.14	0.25	0.56	1240
X81 th105(I)	0.21	0.39	0.54	1720
ICC 5810(D)	0.09	0.29	0.31	1160
ICC 11524(D)	0.14	0.28	0.20	1160
F(Prob)	.0001	.0005	-	.0001

+ Top 0.10 m of the taproot.

Table 6 : Mean Root Length for 1.20 m depth and Shoot dry Weight chickpea at Podding Stage in 1985 at Brookings

Accession	Total Root length (m/m^2)	Shoot weight (g)
ILC 482(K)	141.75	159.7a
ILC 1919(K)	134.52	131.7b
ICC 5810(D)	139.83	86.8b
ICC 11524(D)	114.75	89.5b
F(Prob)	.7681	.0095

Means in the same column and followed by the same letter are not significantly different.

Samples were also taken at podding stage (field experiment 1985) for root length measurements. Total root length was not significantly different among accessions, however shoot weight was less for Desi than Kabuli types (Table 6). Although total root length was not significantly different , accessions showed differences for root length at the top of the profile (Fig 3). The accessions depth interaction was highly significant. Accesions which showed higher root lengths at surface levels (ICC 5810 and ILC 482) showed rapid decreases in length at depths below 0.40 m (Fig 3). Root length density decreased with depth. Approximately 90% of total root length (1.20 m depth) was located in the top 0.70 m of the soil profile and beyond this level differences in root length were negligible (Fig 4). Any differences among accessions in root morphology ie. root branching density, taproot diameter, and root length were reduced with depth. As taproot diameter decreased, less branching occured. Large differences in root morphology were primarily restricted to the top part of the soil profile. Similar results were reported for soybean (Raper and Barber 1970; Mitchell and Russell 1971) and Chickpea (Nagarajrao et al. 1980). The present results seem to follow a slightly different trend with those obtained for chickpea on the basis of root distribution (weight and length) (Nagarajrao et al. 1980). They concluded that beyond beyond 0.45 m depth differences in root quantities among accessions were not significant. However the present study there are also differences at depths between 0.40 m and 1.00 m. This is also indicated by significant genotype x depth interaction and yet the total length is not

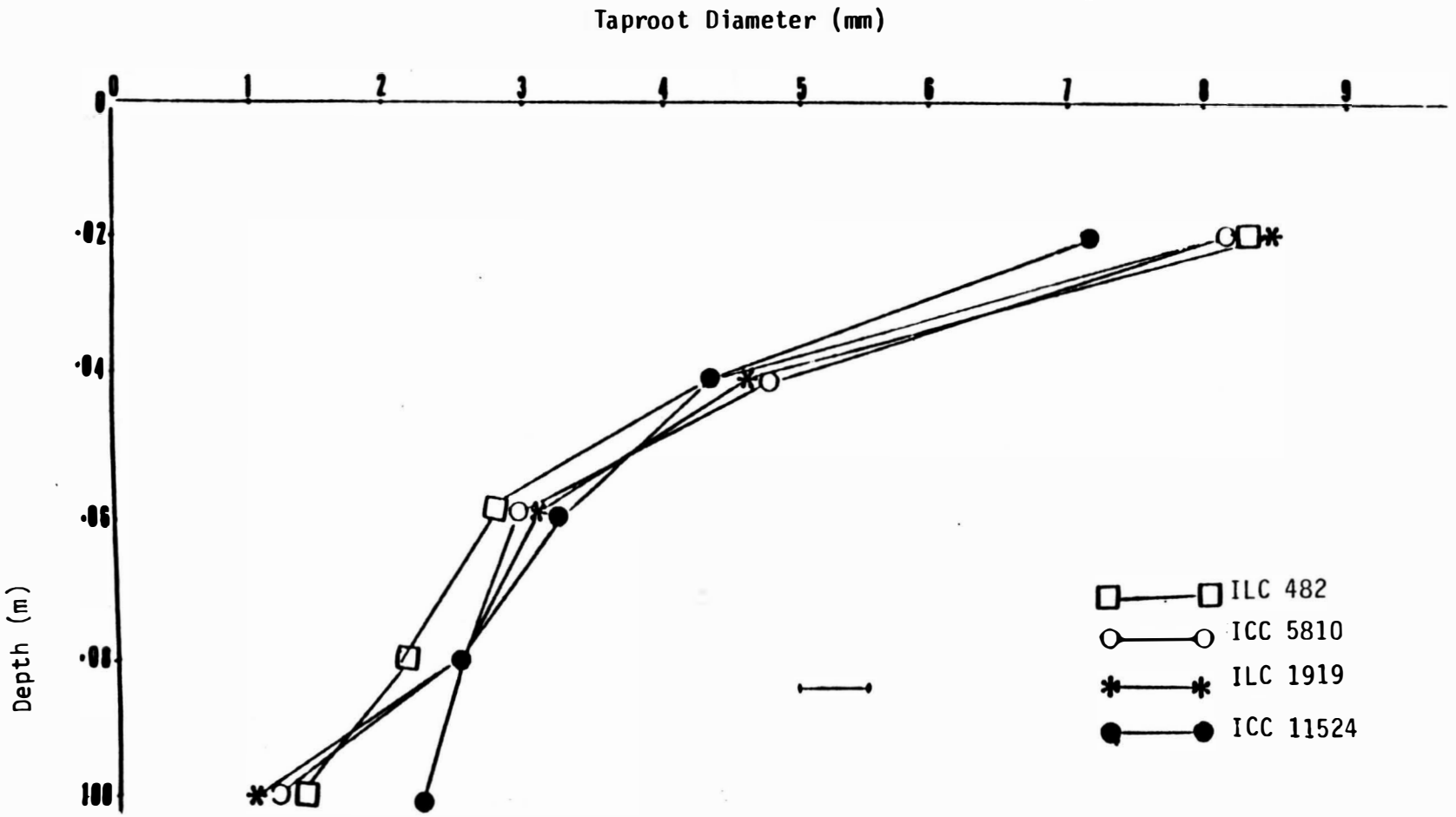


Fig. 1. Reduction in Taproot Diameter with Depth

bar represent SE

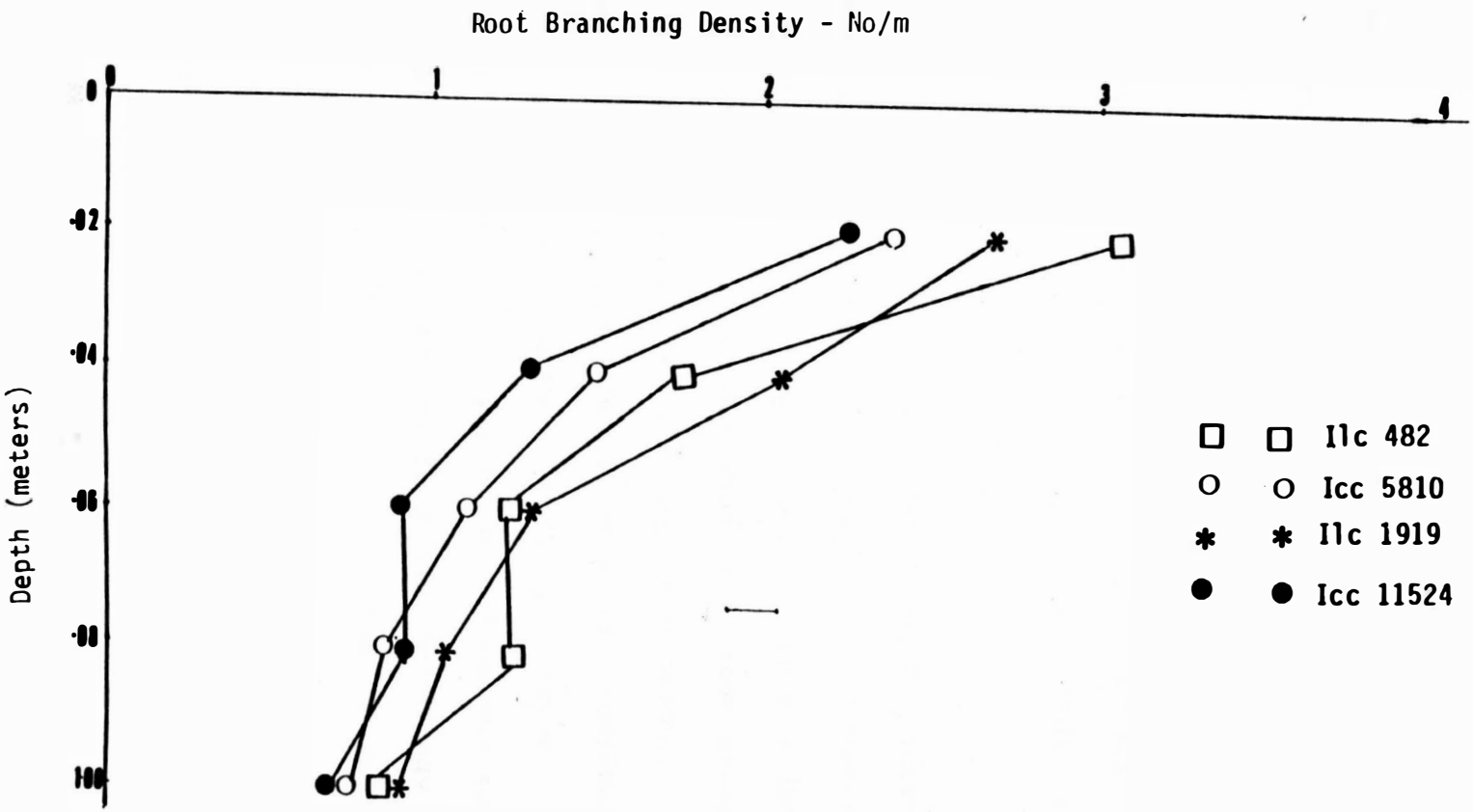


Fig. 2. Root Branching Density Distribution with Depth - Brookings 1985
bar represent SE

significantly different.

There was a problem of (Pythium ultimum Trow.) infection which dried the root system and eventually the whole plant died. There were no particular symptoms on the leaves or stems, but ILC 1919, ILC 482, and ICC 11524 seemed to be severely affected. Even though only disease-free plants were sampled for root analysis, it was impossible to do the same when harvesting for yield because plants were dry at maturity. Seed yield did not show significant differences among accessions possibly due to disease.

Generally, plants of large-seeded accessions are bigger than small-seeded ones and this seems to be reflected in the root systems. Kabuli types, being bigger plants, require a large root system for support or anchorage and thus high root branching density could therefore be suggestive of a large root system. The results seem to suggest root branching density as a fairly consistent characteristic and therefore may be used for classifying genotypes. Branching density is easier to study than excavating the whole root system. Our evidence suggests that major differences in root morphology are primarily located within the top 0.20 m of the soil profile. If root system development has priority over shoot growth early in the season then perhaps branching density could be studied early in the life of a plant and reduce expense and labor requirements. Greenhouse studies could provide more rapid and less tedious methods for screening varieties for root branching density. Since Desi types are smaller plants with less root branching density, they could possibly be planted at higher

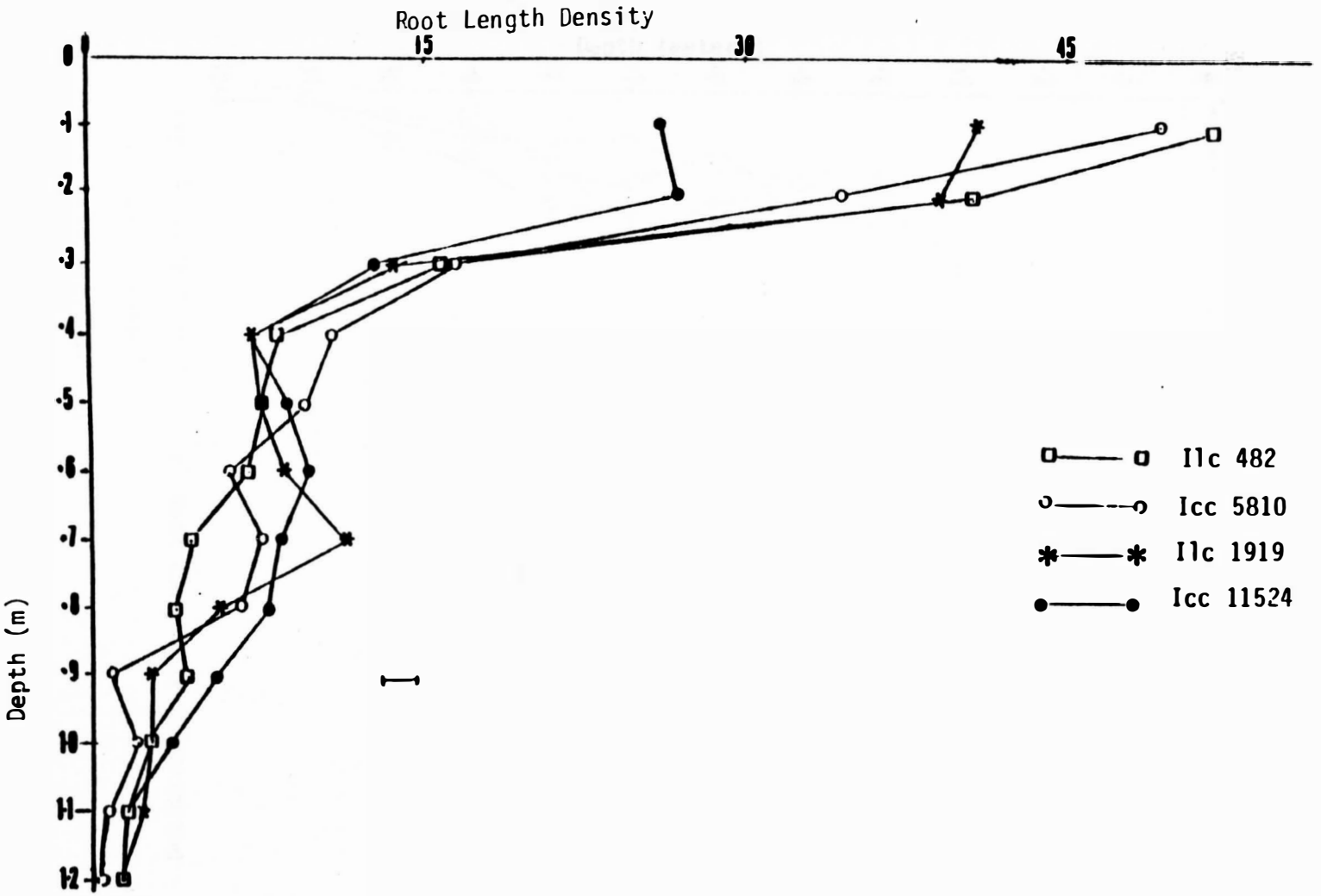


Fig. 3. Root Length Density 5-cm from Chickpea Plant Growing in the Field as Determined by Line Intersect Method.

bar represent SE

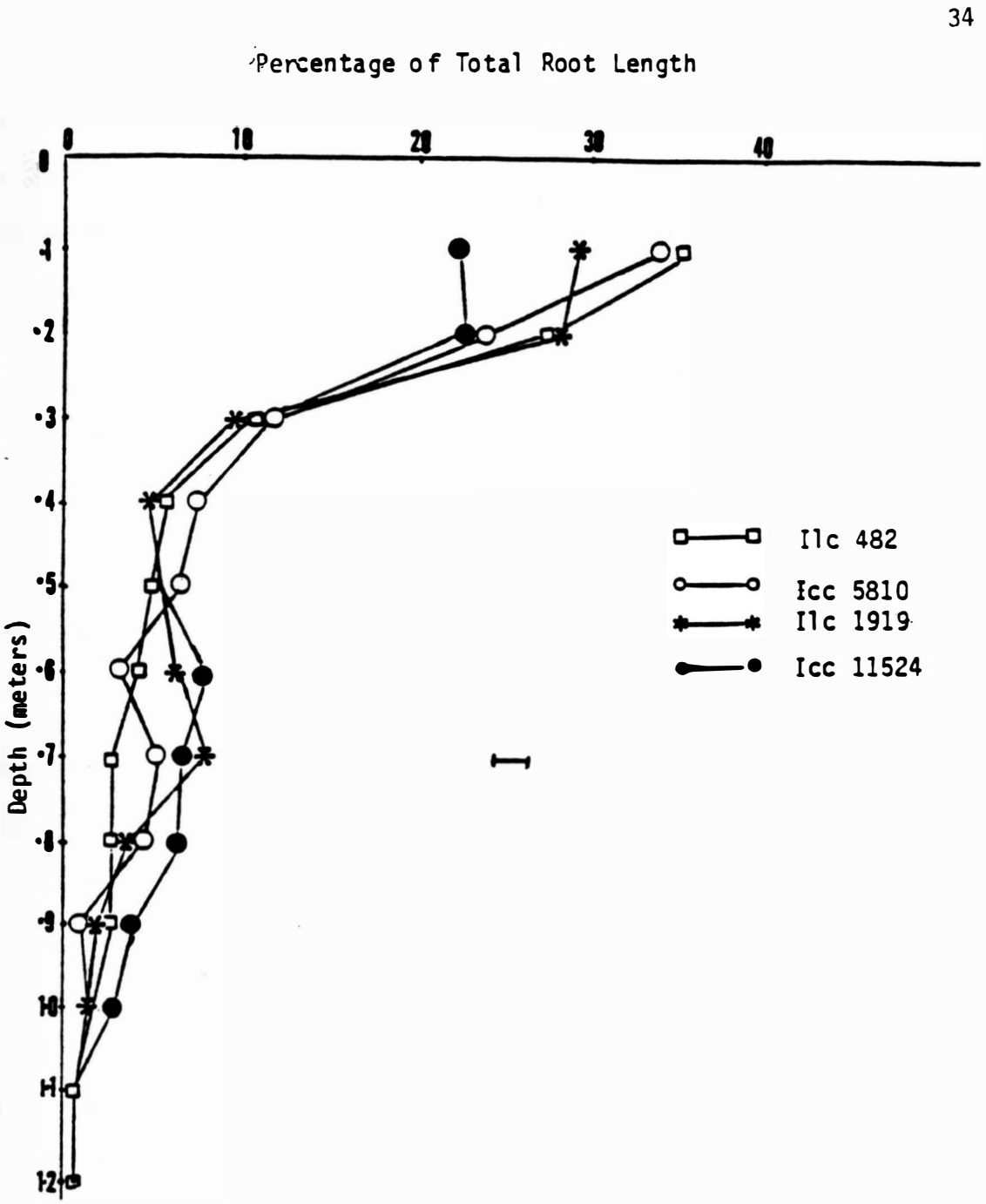


Fig. 4. Percentage of Total Root Length as Distributed with depth

bar represent SE

populations with reduced competition. The density of root branching appears to be a more consistent indicator of genotypic differences as compared to other measured variables under both field and greenhouse conditions.

The following section deals with the effect of imposed environmental stresses (salinity/sodicity, temperature and moisture) on the stability of chickpea root development.

Enviromental Effects on Root Morphology

Salinity/Sodicity

Figs. 5, 6, & 7 show experimental results on screening for tolerance to salt and water stress. Responses to salinity and water stress were varied and different depending on accession, osmoticum, and osmotic potential (Table 7). Germination, and radicle and shoot elongation were reduced and almost inhibited at certain osmotic potentials. A wide variability in response to water potential and the different ions was observed among chickpea accessions in germination, and radicle and shoot growth. There were inherent differences in germination of different accessions as indicated by germination in distilled water (control) (Fig 5a-f). Low germination in distilled water is possibly due to anoxia. Positive and negative responses of germination to Na^{+} (Figs 5c, e, & f) and Ca^{+2} and (Figs 5a & b) relative to Mannitol were observed. Negative effect of Na^{+} and Ca^{+2} in germination may be indicating adverse effect of the ions while positive effect may be suggestive of nutritive contribution of the ions to

germinating seeds. Negative osmotic potential effect on germination is illustrated in Fig. 5d. Assuming that the effects of mannitol are primarily osmotic in nature then it would appear that genotypic variability exists for germination under low water potentials, and high salinity and sodic levels.

Although different root characteristics were reduced by salinity, pod and seed production (tables 13 and 14) seemed to be increased in highly saline soils as was also observed by Muchanda and Sharma (1980). The seeds from the plants grown on Ryan uncultivated soils were shrivelled, discolored, and smaller in size compared to seed from other soils. The poor quality of seed could be a result of reduced efficiency in photosynthate production due to discolored leaves. The effect of the major elements (N, P, K) on root behavior needs to be explored in order to understand the influence of different soils.

Moisture Stress

Plants grown in low moisture were severely stressed and appeared wilted, seemed less vigorous, and exhibited stunted growth. Under high moisture conditions, the root system highly proliferated and covered the whole rooting media, the roots appearing fresh and fragile. Low moisture reduced the root system to covering only a small portion of the soil surface and with the rest of the root system degenerated. Soil samples were taken before harvest to determine water content at the different depths (20, 40, 60, and 08 mm) in the pot. Moisture was not distributed equally in the pot. The top few millimeters of soil were wetter and the roots in this region experienced better conditions than

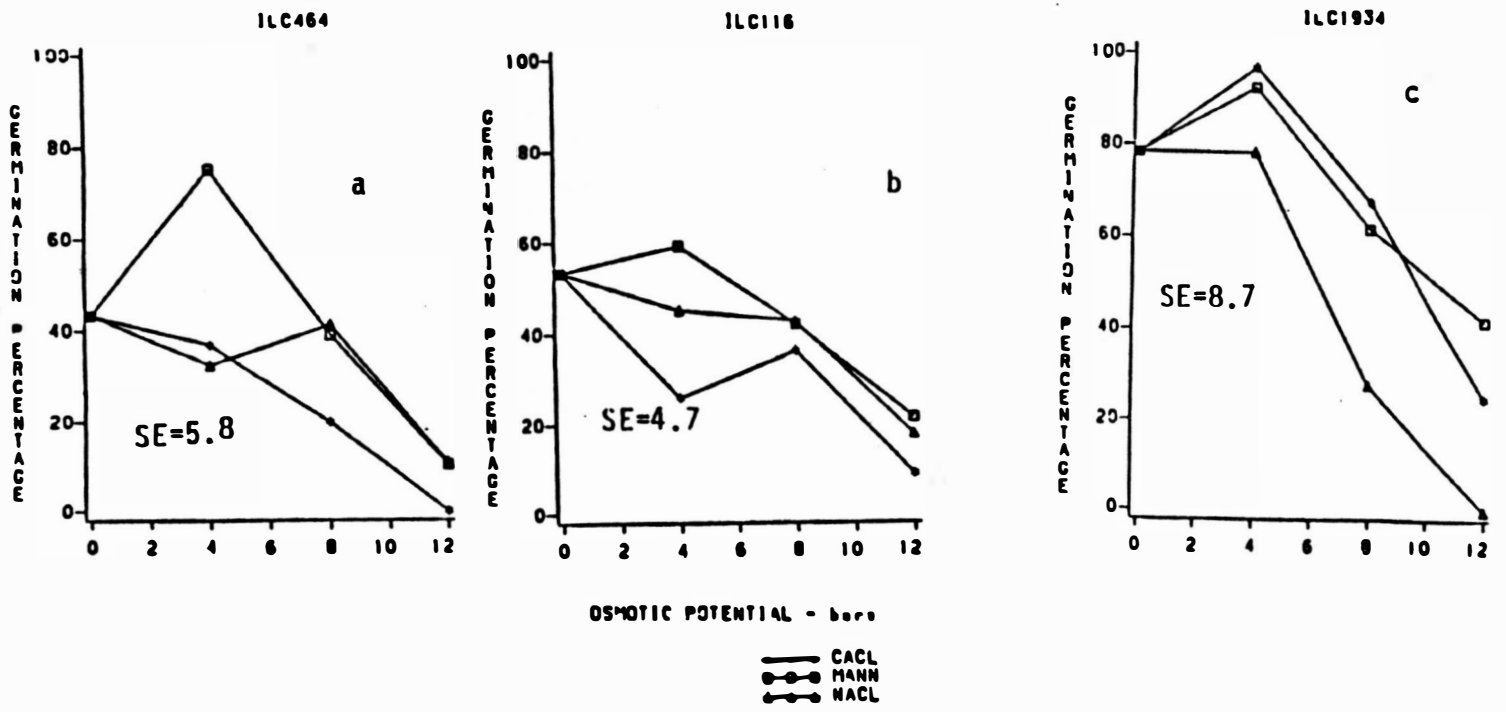


Fig. 5. Effect of Salinity /Sodicity and Water Potential on Germination

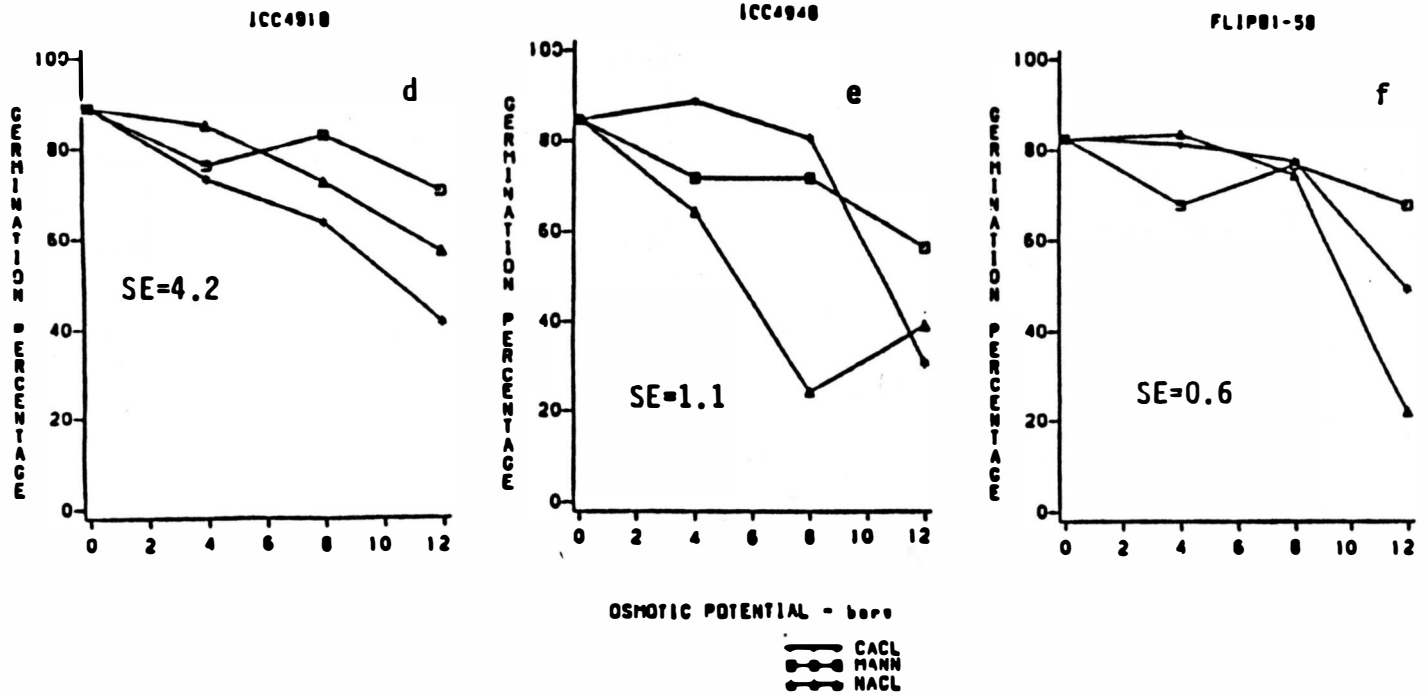


Fig. 5 cont. Effect of Salinity/Sodicity and Water Potential on Germination

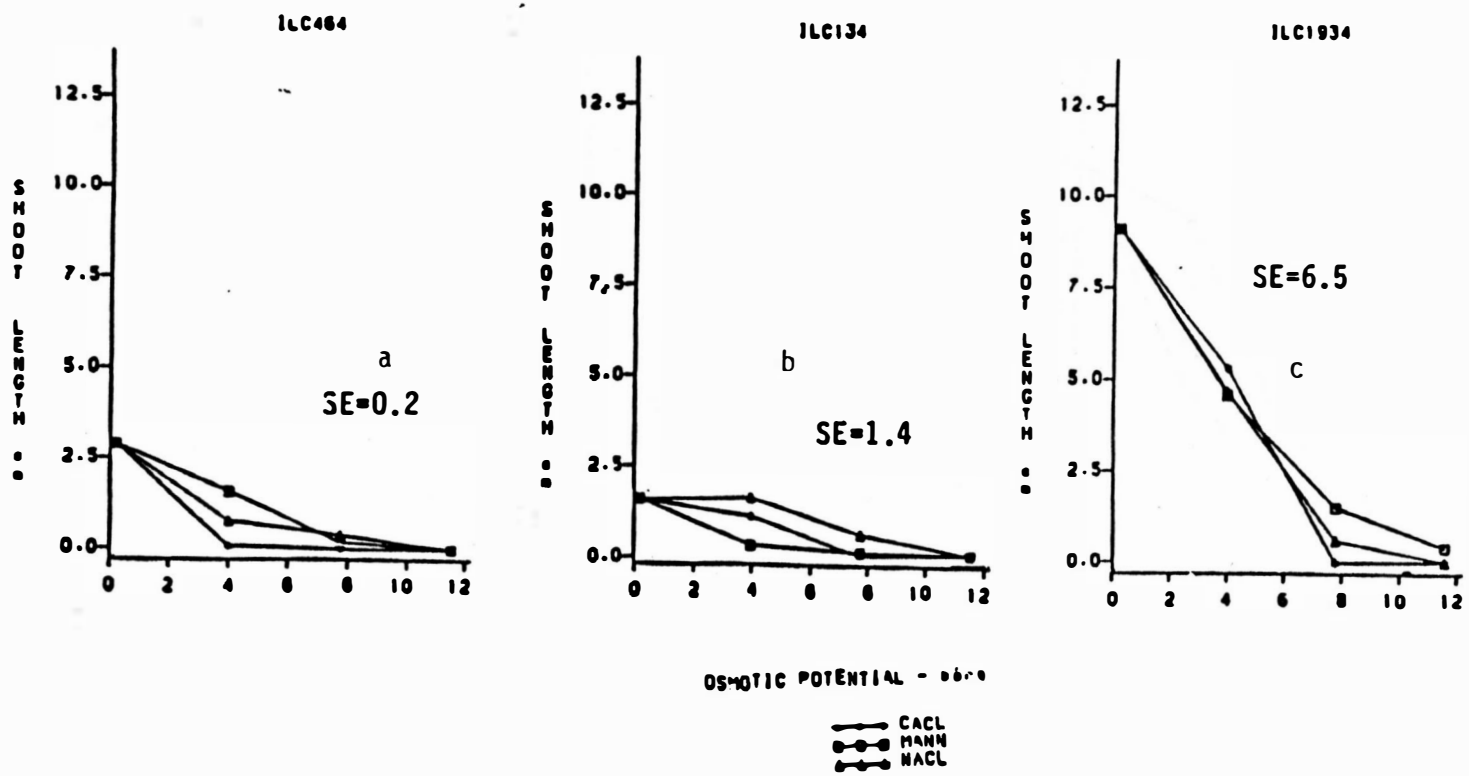


Fig. 6. Effect of Salinity/Sodicity and Water Potential on Shoot Growth

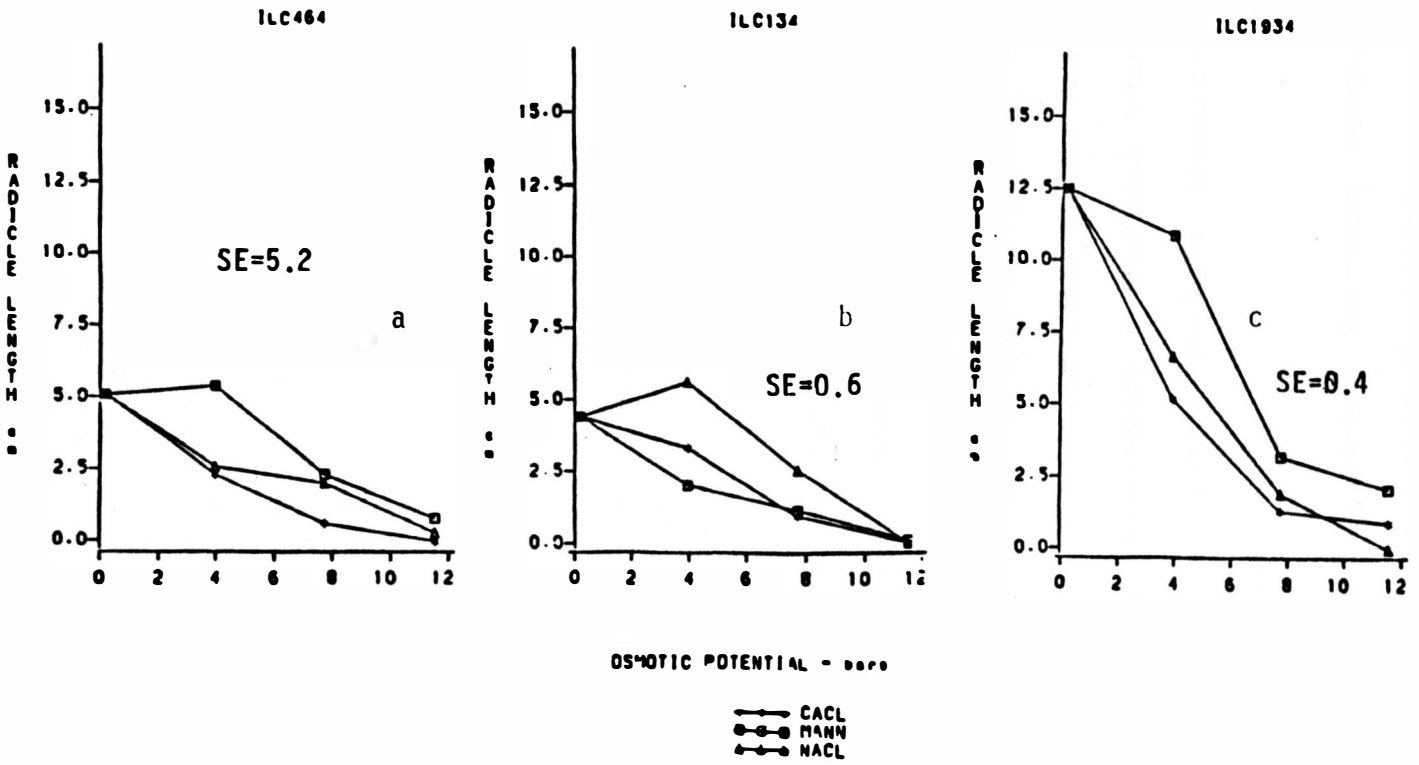


Fig. 7. Effect of Salinity/Sodicity and Water Potential on Radicle Growth

Table 7 : Analysis of Variance Table For Salinity - Osmoticum Experiment

Source	Df	Shoot Length	Radicle Length	Germination
accession(a)	24	234**	446**	113081**
solute(s)	2	91**	671**	23316**
a x s	48	15**	39**	11102**
osmotic pot.(o)	3	8422**	17046**	1168294**
a x o	72	71**	99**	6468**
s x o	6	65**	195**	30669**
a x s x o	144	148**	25**	4740**

** significant at the 0.01 level.

Variability in response to Na^+ and Ca^{++} existed among varieties for both radicle and shoot elongation. Na^+ and Ca^{+2} reduced growth relative to mannitol for a number of chickpea lines (Figs. 7a & c, 6b & c). On the whole, ILC 134 showed poor performance, but Na^+ and Ca^{+2} seemed to give positive radicle and shoot growth relative to the control (Fig 6a & c). Large accession x treatment interactions indicated a differential response among chickpea accessions and therefore a possibility for selection.

Variability in response to salinity has been observed by several authors between and within species at germination stage; rice (Bal and Chattopadhay 1985); sorghum and wheat (Devitt et al. 1984); alfalfa, (Allen et al. 1985); Triticale, (Noryln and Epstein 1984); spring

wheat (Kingsbury and Epstein 1983) and chickpea (Kheradnam and Ghorashy 1973). Positive effects of root elongation in response to Na^+ were reported in wheat (Devitt et al. 1984). The positive effects of Na^+ on some of the tested chickpea accessions at low osmotic potentials however are difficult to explain.

Although tolerance at germination stage does not tell us what will happen at later stages of plant development it is a starting point in narrowing the germplasm to manageable numbers for greenhouse or field studies. Studies by Francois et al. (1984) indicated that sorghum was more salt tolerant at germination than at any other growth stage. This emphasises the need to confirm any results obtained at germination with tolerance at later growth stages.

SOILS

The soils used were;

Ludden cultivated	0.7 mmHo/cm.
Ludden uncultivated	0.7 mmHo/cm.
Ryan cultivated	0.7 mmHo/cm.
Ryan uncultivated	4.0 mmHo/cm.
Greenhouse mixture	0.7 mmHo/cm.

Accession ILC 134 showed poor germination which was most probably a result of anoxia, which some chickpea lines may be sensitive to (Crawford and Zochowski 1984). Yellowing at the edges of leaves were observed at flowering on plants grown in the Ryan uncultivated soil and seemed to be worse on accessions ICC 5810 and ICC 11524.

Results indicated significant differences among accessions and among soils, and the accession x treatment interaction was significant for root branching density (Table 8), indicating a differential response to different soils. Root branching was increased under certain soils; ILC 482, ILC 134 and ICC 11524 had the highest root branching density in Ludden cultivated and ICC 4918 in Ludden uncultivated. The differences are possibly due to nutrition. Ludden cultivated had high P levels compared to Ludden uncultivated. Although Ryan uncultivated also had high P levels it produced the lowest root branching densities for ILC 134, ICC 11524 and ICC 4918. This is probably due to the high Ec and soluble sodium levels in this soil. The greenhouse mixture was of a completely different texture, and also low in phosphorus and potassium. It ranked third in root branching density for all accessions. All characters were influenced by salinity. The most saline soil had higher shoot:root ratios (Table 9). Shoot dry weights were highest in Ludden uncultivated for all varieties (Table 10) and root weights were higher in Ryan cultivated (Table 11) for all accessions.

Table 8 : Analysis of Variance Table for Soil Experiment

		MEAN SQUARES		CHI-SQUARES		
Source	DF	Shoot Weight	Root Weight	Root Branching Density	Pod No.	Seed No.
Accession	3	2.88**	0.26**	161.28**	17.71**	38.48**
Treatment	4	3.62**	0.32**	47.52**	5.59**	8.60**
V x T	12	0.17ns	0.02ns	24.52**	5.05ns	7.95ns

** significant at 0.01 level of probability.

Table 9 : Effect of Soils on Shoot: Root Ratio

Accession	Ludden uncultivated	Ludden cultvated	Ryan uncultivated	Ryan cultivated	Green-House mixture
ICC 4918(D)	2.69	1.91	3.25	2.18	1.73
ICC 11524(D)	2.49	1.78	3.28	1.63	1.68
ILC 482(K)	2.81	2.32	2.80	1.69	2.32
ILC 134(K)	3.58	2.45	3.88	2.20	3.63

those deeper in the pot (Appendix C).

Analysis of variance showed highly significant differences among accessions and between moisture levels. Differential response to moisture stress among accessions was shown by a significant accession x treatment interaction (Table 15). Shoot (Table 16), root fresh weight (Table 17), total root length (Table 18), taproot diameter (Table 19) and root branching density (Table 20) were significantly different between moisture levels. The major differences among accessions in all characters were found in the high soil moisture treatment. High moisture promoted both root and shoot growth and low shoot : root ratios (Table 21). The shoot/root ratio increased as moisture decreased probably due to root degeneration.

Accession x treatment interactions were highly significant for root branching and root fresh weight indicating differential response of accessions to moisture stress. Root branching decreased with moisture level, but at 0.06g level, it was promoted for ICC 4918 and ICC 11524 and for ILC 134 and ILC 482 it decreased with a decrease in moisture (Table 20). Root weight followed the same trend.

For accession ICC 4918 shoot growth was promoted relative to root growth at high moisture levels (high ratio). For other accessions, the highest shoot/root ratio was observed at low moisture levels, 0.06 for ICC 11524 and ILC 482 and 0.15 for ILC 134 (Table 21).

The 0.26 /0.06 cyclic treatment was included to test whether a period of rewatering might stimulate greater root branching or if root

Table 10 : Effect of Soil on Shoot Dry Weight

Accession	Ludden unculti-vated	Ludden culti-vated	Ryan unculti-vated	Ryan culti-vated	Green-House mixture	Means
ICC 4918(D)	1.32	0.61	0.39	0.48	0.33	0.63
ICC 11524(D)	1.32	0.82	0.82	0.57	0.62	0.83
ILC 482(K)	2.08	1.28	1.40	0.54	0.95	1.25
ILC 134(K)	1.86	1.30	1.32	0.77	1.27	1.30
Mean	1.64	1.00	0.98	0.59	0.79	1.00

LSD 0.05(accession)=0.37
LSD 0.05(soils)=0.33

Table 11 : Effect of soils on root weight

Accession	Ludden unculti-vated	Ludden culti-vated	Ryan unculti-vated	Ryan culti-vated	Green-House mixture	Means
ICC 4918(D)	0.49	0.32	0.12	0.22	0.19	0.27
ICC 11524(D)	0.53	0.46	0.25	0.35	0.37	0.39
ILC 482(K)	0.74	0.55	0.50	0.32	0.41	0.50
ILC 134(K)	0.52	0.53	0.34	0.35	0.35	0.42
Means	0.57	0.46	0.30	0.31	0.33	0.40

LSD 0.05(accession)=0.13
LSD 0.05(soils)=0.11

branching was maintained at lower water potentials. It gave the lowest density for root branching (Table 20), probably because the soil column was dry throughout for a period of time as compared to getting a small amount of water every day (0.06 g. moisture level). Evidence suggests that for a dropping water table, moisture stress will promote proliferation of the root system at greater soil depths (Follett et al. 1974). It was not the case in this situation primarily because with the restricted growth media there were no moisture reserves to be exploited. The results seem to confirm findings by Garay and Wilhelm (1983) that under drought conditions root density varies with depth of moisture.

Temperature

Analysis of variance indicate significant differences among accessions, temperatures and accession x temperature interactions (Table 22). Root branching density was taken for the entire length of the radicle which included the elongation region and may not reflect differences among accessions in root branching but rather their rate of root initiation. Variability exists between varieties in shoot (Table 23) and radicle length (Table 24), taproot diameter (Table 25) and root initiation as indicated by root branching density after 10 days (Table 26),while the temperature at 10°C reduces growth and prevents secondary root development.

Optimum temperature for root initiation and branching is 25°C for all accessions except for ILC 134 which seem to be performing fairly consistently at temperatures between 20°C and 30°C (Table 26). Kabuli

Table 12 : Effect of Soil on Root Branching Density (no./m)

Accession	Ludden unculti-vated	Ludden culti-vated	Ryan unculti-vated	Ryan culti-vated	Green-House mixture
ICC 4918(D)	1260	1000	650	880	950
ICC 11524(D)	1170	1340	980	1330	1300
ILC 482(K)	2280	2340	1630	1400	1830
ILC 134(K)	1460	1730	1090	1260	1380

Table 13 : Effect of Soils on Pod Production (no./plant)

Accession	Ludden unculti-vated	Ludden culti-vated	Ryan unculti-vated	Ryan culti-vated	Green-House mixture
ICC 4918(D)	25	18	24	17	16
ICC 11524(D)	28	26	30	16	18
ILC 482(K)	18	20	27	20	22
ILC 134(K)	14	12	14	8	12

Table 14 : Effect of Salinity on Seed Production (no./plant)

Variety	Ludden unculti-vated	Ludden culti-vated	Ryan unculti-vated	Ryan culti-vated	Green-House mixture
ICC 4918(D)	33	22	30	22	18
ICC 11524(D)	38	32	31	18	24
ILC 482(K)	17	20	25	20	20
ILC 134(K)	12	12	12	7	9

types initiate greater numbers of roots than Desi types overall (Table 26). Figs. 8 & 9 indicate common optimum temperatures for all accessions for both root and shoot length. Diameter varied between temperarures and there was a differential response to temperatures. Unlike cotton (Arndt 1945), shoot and radicle elongation have a common optimum temperature and sub and supraoptimal temperatures reduce growth. Alternating temperatures seemed to give the same effect as their average constant temperature with the possible exception of shoot length measurements in which the lowest temperature of the cycle appeared to control expression of this trait (Table 23).

Table 15 : Analysis of Variance Table for Moisture Experiment

		M E A N S Q U A R E S					CHI SQUARES
Source	DF	Shoot Weight	Root Weight	Taproot Length	Total Root Length	Root Diameter	Root Branching Density
Accession	3	3.14**	2.62*	23.67*	17.46ns	5.51**	12.93**
Treatment	4	15.50**	60.48**	17.78ns	491.00**	2.52**	191.17**
V X T	11	1.07**	2.88**	7.83ns	17.10ns	0.32ns	55.55**

*,** significant at 0.05 and 0.01 levels, respectively.

Table 16 : Effect of Moisture Stress on Shoot Weight (grams)

	TREATMENT (g. of water / g. of soil)				
	0.26	0.15	0.08	0.06	0.26/0.06
Accession	(0)	(0.33)	(6)	(12)	(0/12)
ILC 482(K)	4.59a	1.33a	0.84a	1.05a	0.98a
ILC 134(K)	4.91a	2.29b	0.97a	0.97a	-
ICC 4918(D)	1.96b	0.91c	0.62a	0.91a	0.34a
ICC 11524(D)	2.59b	0.74c	0.38a	0.96a	0.16a

Means within a column followed by the same letter are not significantly different at 0.05 level of probability.
( ) number in paranthesis indicate soil water potential in -bars.

Table 17 : Effect of Moisture Stress on Root Weight (grams)

	TREATMENT (g. of water / g. of soil)				
Accession	0.26 (0)	0.15 (0.33)	0.08 (6)	0.06 (12)	0.26/0.06 (0/12)
ILC 482(K)	7.91a	1.42a	0.32a	0.36a	0.65a
ILC 134(K)	6.98a	1.23a	0.69a	0.50a	-
ICC 4918(D)	3.24b	1.36a	0.48a	0.67a	0.16a
ICC 11524(K)	4.72b	0.47a	0.24a	0.50a	0.13a

Means within a column followed by the same letter are not significantly different at 0.05 level of probability.
( ) number in paranthesis indicates soil water potential in -bars

Table 18 : Effect of Moisture Stress on Root Length per plant (meters)

	TREATMENT (g. of water / g. of soil)				
accession	0.26 (0)	0.15 (0.33)	0.08 (6)	0.06 (12)	0.26/0.06 (0/12)
ILC 482(K)	22.40a	2.96a	0.57a	0.65a	2.20a
ILC 134(K)	16.10b	2.27a	0.92a	0.58a	-
ICC 4918(D)	10.26c	2.88a	1.27a	1.64a	0.18a
ICC 11524(D)	14.05c	0.67a	0.23a	0.55a	0.12a

Means within a column followed by the same letter are not significantly different at 0.05 level of probability.
( ) number in paranthesis indicate soil water potential in -bars.

Table 19 : Effect of Moisture Stress on Root Diameter (mm)

accession	TREATMENT (g. of water / g. of soil) 0.26 (0)	0.15 (0.33)	0.08 (6)	0.06 (12)	0.26/0.06 (0/12)
ILC 482(K)	3.60a	2.34a	2.64a	2.44a	2.13a
ILC 134(K)	4.78b	3.86b	3.35a	4.27b	-
ICC 4918(D)	2.84a	2.84a	1.83a	2.44a	1.93a
ICC 11524(D)	3.45a	2.95a	2.54a	3.45a	1.83a

Means within a column followed by the same letter are not significantly different at 0.05 level of probability.
( ) number in paranthesis indicate soil water potential in -bars.

Table 20 : Effect of Moisture Stress on Root Branching Density (no./m)

Accession	TREATMENT (g. of water / g. of soil) 0.26 (0)	0.15 (0.33)	0.08 (6)	0.06 (12)	0.26/0.06 (0/12)
ILC 482(K)	2049	1824	1286	930	560
ILC 134(K)	3050	1444	1320	914	-
ICC 4918(D)	1195	750	828	1328	596
ICC 11524(D)	1131	1286	1180	1100	714

( ) number in paranthesis indicate soil water potential in -bars.

Table 21 : Effect of Moisture Stress on Shoot: Root Ratio

	TREATMENT (g. of water / g. of soil)				
Accessionn	0.26 (0)	0.15 (0.33)	0.08 (6)	0.06 (12)	0.26/0.06 (0/12)
ILC 482(K)	0.58	0.94	2.62	2.91	1.51
ILC 134(K)	0.70	1.86	1.40	1.94	-
ICC 4918(D)	0.60	0.67	1.29	1.36	2.12
ICC 11524(D)	0.55	1.57	1.58	1.92	1.23

( ) number in paranthesis indicate soil water potential in -bars.

Table 22 : Analysis of Variance Table for Temperature Experiment

		M E A N S S Q U A R E S			Chi squares
Source	DF	Shoot Length	Radicle Length	Root Diameter	Root Branching
Accession(a)	3	245.90**	496.57**	48.10**	610.40**
Temp(t)	5	3858.00**	5876.46**	11.29**	596.66**
a x t	15	62.903**	78.38**	0.95ns	299.54**

** significant at 0.01 level of probability.

Table 23 : Effect of Temperature on Shoot Growth (length in mm)

	T E M P E R A T U R E (°C)						
Accession	10	15	20	25	30	20/30	Mean
ICC 11524(D)	7	30	105	172	131	108	93
ICC 4918(D)	1	37	82	143	153	86	84
ILC 134(K)	0	22	68	105	152	70	70
ILC 482(K)	12	48	110	161	137	104	96
Means	0.52	3.49	9.18	14.58	14.34	9.23	8.55

LSD(accession)=25
LSD(temp.)=21
LSD(axt)=51

Table 24 : Effect of Temperature on Radicle Growth (length in mm) of Chickpea

	T E M P E R A T U R E (°C)						
Accession	10	15	20	25	30	20/30	Mean
ICC 11524(D)	51	111	191	218	210	223	167
ICC 4918(D)	38	93	172	243	163	198	151
ILC 134(K)	33	64	188	172	191	184	139
ILC 482(K)	56	127	217	238	203	214	176
Mean	44	99	192	218	192	205	155

LSD(accession)=43
LSD(temp.)=35
LSD(axt)=8.54

Table 25 : Effect of Temperature on Root diameter (mm) of Chickpea

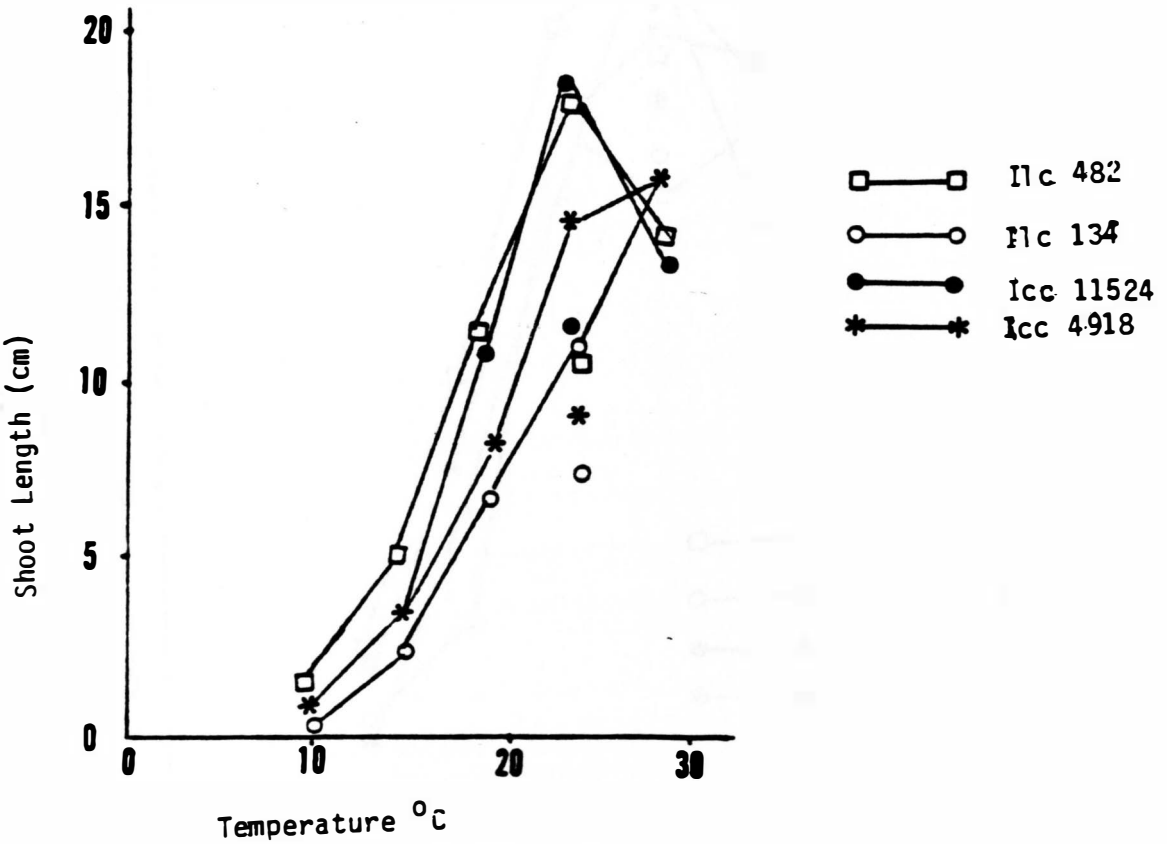
	T E M P E R A T U R E (°C)						
Accession	10	15	20	25	30	20/30	Mean
ICC 11524(D)	20	21	23	25	22	25	28
ICC 4918(D)	22	30	26	28	20	26	26
ILC 134(K)	30	38	37	37	29	37	35
ILC 482(K)	23	31	26	30	23	28	27
Means	24	30	28	30	23	29	27

LSD(variety)=5
LSD(temp.)=4
LSD(axt)=9

Table 26 : Effect of Temperature on Root Initiation and branching (no./plant) of chickpea

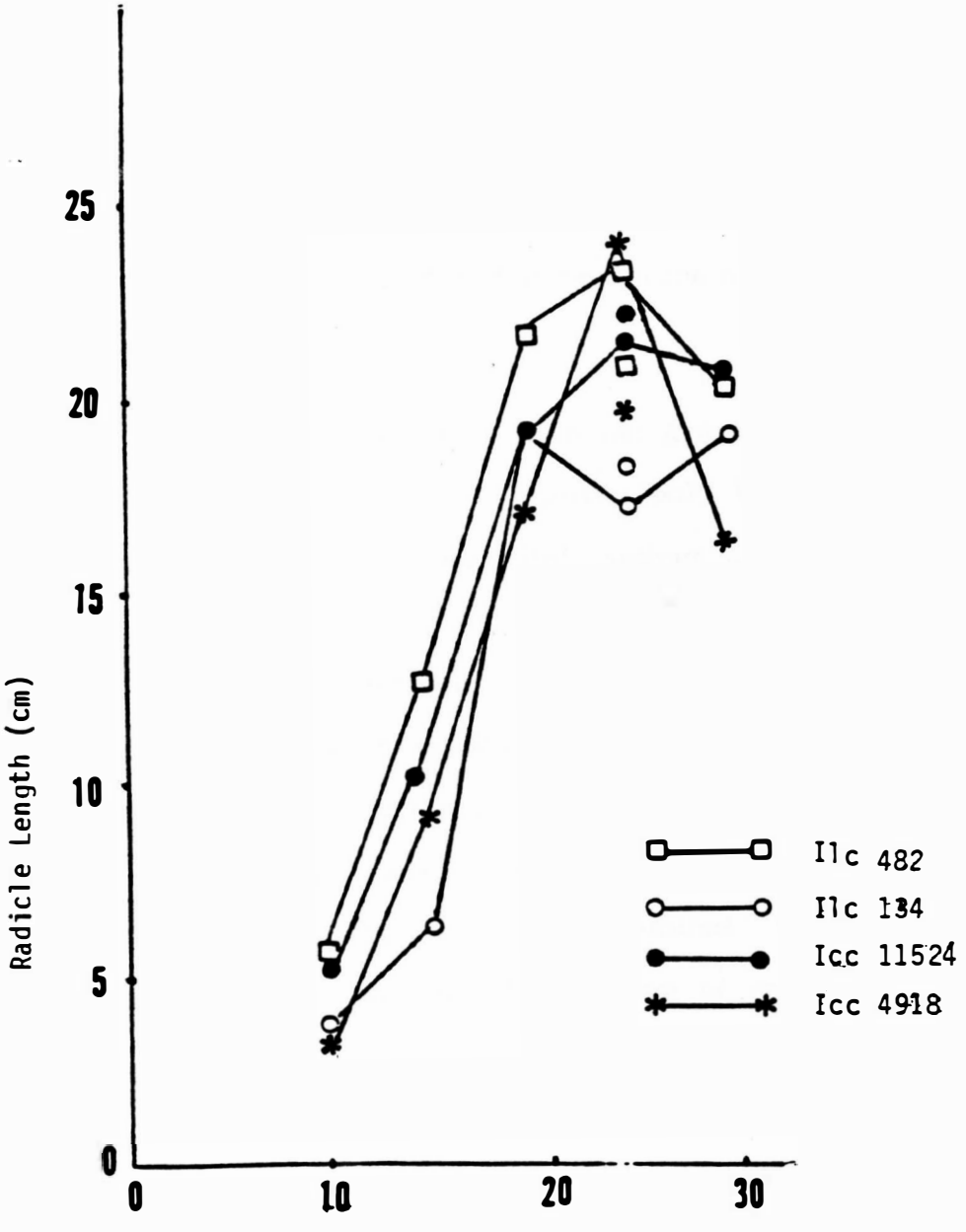
	T E M P E R A T U R E (°C)					
Accession	10	15	20	25	30	20/30
ILC 482(K)	0	2772	4618	6050	4544	5178
ICC 4918(D)	0	1604	3333	4751	3808	3417
ICC 11524(D)	0	63	2778	3323	2521	2658
ILC 134(K)	0	47	4477	4632	4208	4718

Fig. 8. Effect of Temperature on Shoot Elongation



unconnected points are for alternating temperatures

Fig. 9. Effect of Temperature on Radicle Elongation



unconnected points are for alternating temperatures

SUMMARY AND CONCLUSIONS

The objective of the study was to examine root characteristics of selected chickpea genotypes, from Kabuli and Desi types. The effect of enviromental conditions on stability of root development was assessed with respect to salinity, temperature, and moisture stresses. Field experiments were conducted for two cropping seasons at Brookings and Highmore, South Dakota.

Salinity experiments involved greenhouse studies using soils of the following electrical conductivities(ec): 0.7, and 4.0 mmHo/cm and laboratory studies using mannitol, sodium chloride and calcium chloride solutions with osmotic potentials of; 0, -4, -8, and -12 bars. A moisture stress experiment was conducted in the greenhouse with moisture treatments corresponding to; 0, -0.33 bars, -6 bars, -12 bars and 0 and -12 bars cycles. Salinity and moisture stress reduced root branching density, taproot diameter, shoot weight, and root weight. However, Kabuli types still exhibited high ranking for root characteristics. It seemed the problem of reduction in root branching under moisture stress was complicated by the fact that root degeneration occured and made it difficult to count. Pod and seed production were increased in highly saline soil. However seed was of poor quality, shrivelled, and discolored. Radicle growth , shoot growth, and germination, were reduced and sometimes inhibited at certain osmotic potentials. It appeared osmotic and ion effects operated

depending on genotype and osmoticum. Sometimes Na^{+} and Ca^{++} gave favourable effects in germination, radicle, and shoot elongation.

Chickpea accessions were germinated under laboratory conditions at constant temperatures of; 10, 15, 20, 25, 30, and alternating 20 and 30°C (8 and 16 hrs respectively) for 10 days. There was a temperature optima for radicle and shoot growth, below and above which growth was reduced. The optimum temperature for growth was 25°C while 10°C was inhibitory to growth and root branch initiation, which only started at 15°C. Genotype x enviroment interactions were large, indicating differential response to temperature.

The results of this study showed variability in root morphology among chickpea genotypes, notably between Desi and Kabuli types. The pattern is such that Kabuli types ranked high in the measured attributes (root branching density, taproot diameter and root length). Major differences in root morphology were located within the top 18cm of the soil profile, hence root behaviour in this region could be characteristic of root morphology in chickpea. Root branching density in particular is a consistent character which may be used as a criteria for root system studies. Root morphology of chickpea varies with environment but the trend is maintained in terms of magnitude. Kabuli types maintain consistency in root morphology under different environmental conditions. Large genotype x environment interactions suggest a possibility of selection for tolerance to adverse environmental conditions. However root studies in the future may involve correlations to genotypic differences which have been identified by other ways.

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APPENDICES

APPENDIX A

List of Accessions Used in Salinity Experiment

ENTRY	ORIGIN	SEED
ILC 519	Egypt	Cream
ICC 4948	India	Brown
FLIP 81-32	ICARDA	Cream
ILC 1934	Iran	Cream
FLIP 80-1	ICARDA	Cream
ICC 5003	India	Brown
ILC 134	Spain	Cream
FLIP 80-2	ICARDA	Cream
ILC 493	Turkey	Cream
ILC 83	Spain	Cream
ICC 10136	India	Brown
FLIP 81-58	ICARDA	Cream
ILC 610	Tunisia	Cream
ILC 464	Turkey	Cream
ICC 4918	India	Brown
ILC 116	Spain	Cream
ILC 1931	Turkey	Cream
FLIP 80-5	ICARDA	Cream
ILC 136	Spain	Cream
ILC 76	Spain	Cream
ILC 165	Tunisia	Cream
ILC 132	Spain	Cream
ILC 254	Turkey	Cream
ILC 135	Spain	Cream

APPENDIX B

Soil Test Results

Soil	OM	P	K	pH	mmHo/cm	Soluble Sodium (meq/l)
Ludden cultivated	2.4	88	990	6.8	0.7	--
Ludden uncultivated	5.7	19	990	6.5	0.7	--
Ryan cultivated	2.7	63	990	6.7	0.7	--
Ryan uncultivated	3.2	98	990	7.3	4.0	32
Greenhouse mixture	2.6	20	165	7.0	0.7	6

APPENDIX C

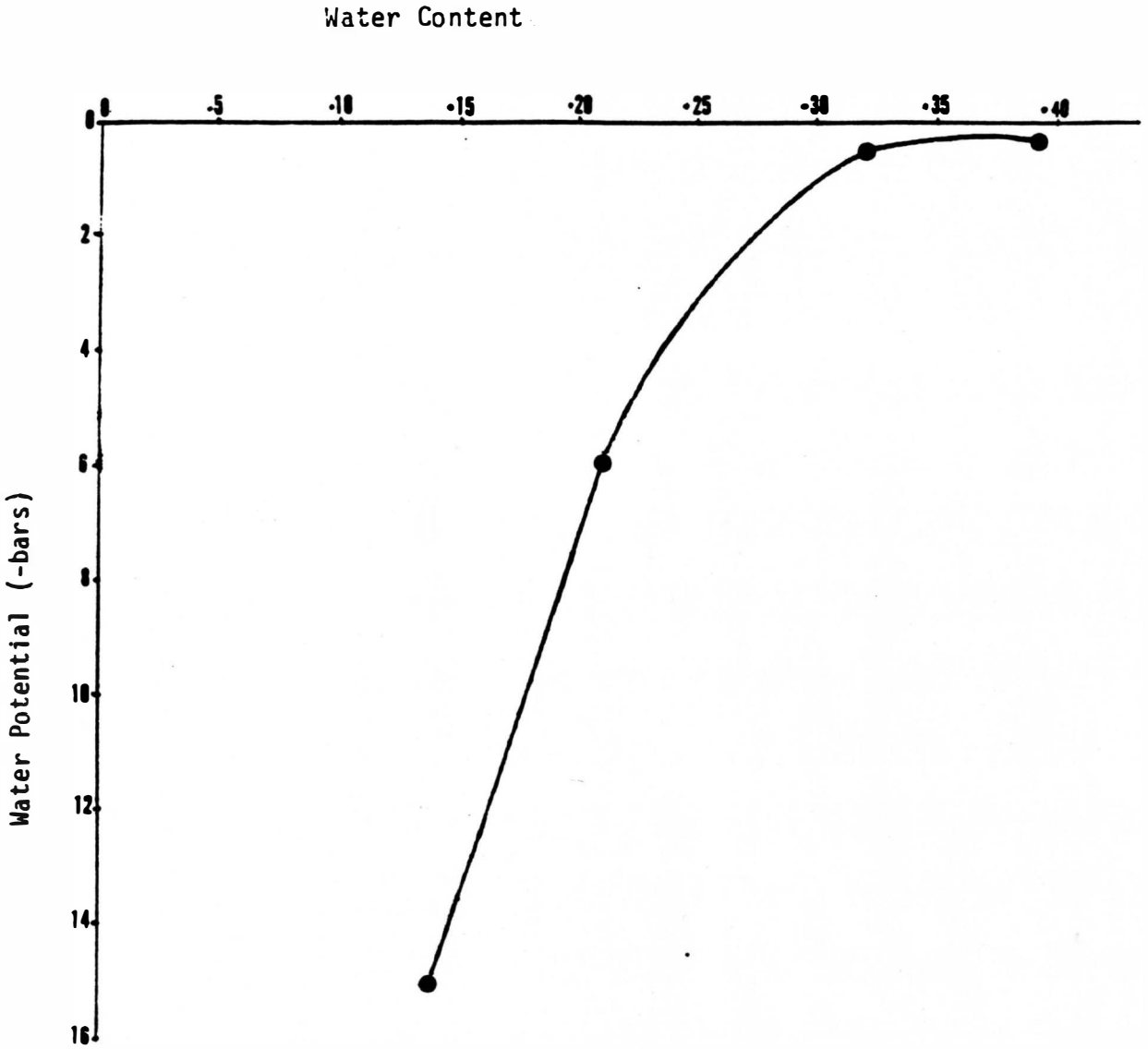
Change in Moisture Content with Pot Depth for Different Treatments

	Moisture level treatments			
Depth	0.06	0.08	0.15	0.26
2	0.16	0.16	0.16	0.29
4	0.10	0.10	0.15	0.25
6	0.08	0.09	0.15	0.23
8	0.02	0.08	0.14	0.23

APPENDIX D

100 Seed Weight for Accessions Used in Root studies

Accession	Weight (g)
ICC 4918	15.6
ICC 5810	14.1
ICC 11524	15.9
ILC 1919	22.9
ILC 482	28.2
ILC 134	43.3



E. Moisture Characteristic Curve