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Genotypic variation in moisture response of chickpea grown under line-source sprinklers in a semi-arid tropical environment

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Abstract

The line-source sprinkler technique was used to compare moisture responses of a range of advanced chickpea (*Cicer arietinum* L.) breeding lines grown on receding soil moisture. Experiments were conducted on a Vertisol soil in peninsular India during the 1985/86 and 1986/87 postrainy seasons. Lines tested displayed a linear response of both aerial biomass and grain yield to moisture applied. Thus use of only two moisture levels, with and without irrigation, would be sufficient to compare moisture responses of chickpea in this environment. Genotypic responses were evaluated on the basis of slopes and intercepts of line-source data. Lines previously identified as drought resistant showed greatest resistance in the present study. Most test lines from breeders had relatively low drought resistance, as indicated by low intercept and intermediate to high slope. This is consistent with the test lines having been selected under different levels of supplementary irrigation in different generations. It is suggested that development of substantially improved drought resistance in this environment will require rigorous selection pressure under a given drought environment. A breeding program under natural receding soil moisture conditions in this environment is feasible because the pattern of receding soil moisture is, or can be made, similar across seasons, thus minimizing environmental variability in relation to genotypic variability.

Keywords: Chickpea; *Cicer arietinum*; Drought resistance; Line-source sprinkler; Moisture response

1. Introduction

The importance of drought as a limitation to growth and yield of chickpea (*Cicer arietinum* L.) increases with a decrease in latitude from the subtropics to the tropics (Saxena, 1984) because of the increase in atmospheric evaporative demand during the chickpea growing season in winter (Saxena and Sheldrake, 1980). This necessitates the use of shorter duration varieties, which can to some extent escape terminal drought and heat stress (Sheldrake and Saxena, 1979). However, within the short-duration group, it is desirable to identify genotypes better able to produce grain under limited and receding soil moisture conditions.

Screening of short-duration chickpea germplasm for drought response has been conducted at ICRISAT Center, near Hyderabad in peninsular India, using treatments with and without irrigation (Saxena, 1987). Relatively resistant (Levitt, 1980) cultivars, such as ICC 4958 and ICC 10448, have been identified. These show consistently greater yields under drought across seasons and in soils differing in water-holding capacity (ICRISAT, 1987).

The treatments used in such screening, with and

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without irrigation imposed on the receding soil moisture situation, provide only two points on a moisture response curve. If genotypes are to be characterized in this respect, the shape of such response curves should be predictable. Line-source sprinkler techniques have been successfully used in other crops to create a moisture gradient suitable for comparing moisture responses of different genotypes (Hanks et al., 1976). We therefore applied this technique to chickpea growing on receding soil moisture on a vertisol in order to:

- characterize moisture response functions for chickpea in this environment;
- examine whether genotypic rankings in drought response previously found persist;
- evaluate the extent of variation in moisture response among sets of advanced lines from breeders;
- suggest an appropriate breeding strategy for improvement of drought resistance in this environment.

2. Materials and methods

Experiments were conducted in the 1985/86 and 1986/87 postrainy seasons on a vertisol (fine montmorillonitic isohyperthermic typic pallustert) at ICRISAT Center (17°30′N; 78°16′E; altitude 549 m) in peninsular India. This soil retains about 200 mm of plant extractable water in the upper 1.5 m of the soil profile (Singh and Sri Rama, 1989).

In 1985/86, the field was prepared into 1.5-m broadbeds-and-furrows (BBF) in north–south direction after surface application and incorporation of 18 kg N ha^{-1} and 20 kg P ha^{-1} as diammonium phosphate. The sprinkler line was laid out parallel to the BBF, with 10 beds on either side of the line. Sprinkler heads were placed at 6-m intervals, with two heads extending beyond each end of the experimental area. Twenty-one chickpea entries, including 15 recently developed breeding lines by chickpea breeders, were grown in plots randomized in four blocks, two on each side of the sprinkler line. Plots were 1 m wide and 15 m long, extending away from the line-source and therefore crossing 10 beds. On each bed, four rows (of 1 m length) were sown 30 cm apart parallel to the BBF direction. Within-row spacing was 10 cm. Chickpea cultivar ICCC 33 was grown as a buffer plot at the outer ends of test rows in each block.

In 1986/87, four blocks of 46 entries, including 40 recently developed lines, were tested. In this season the line-source sprinklers were placed perpendicular to the BBF, as protection against surface runoff during sprinkling appeared unnecessary and this layout allowed planting through a tractor-mounted seed drill. Also, no fertilizer was applied as soil analyses and small plot diagnostic fertilizer trials indicated no growth limitation due to nutrient deficiency. The four blocks were sown on each side of two sprinkler lines. Each plot was 4 rows wide and 15 m long, perpendicular to the line-source. Distance between rows was 30 cm and within rows 10 cm. There was a gap, in the furrow, of 60 cm between plots. Cultivar Annigeri was grown in buffer plots at the ends of test rows in each block.

Control cultivars grown in both seasons were: Annigeri, which is locally adapted; ICC 4958 and ICC 10448, which are drought resistant; ICC 11051 and ICC

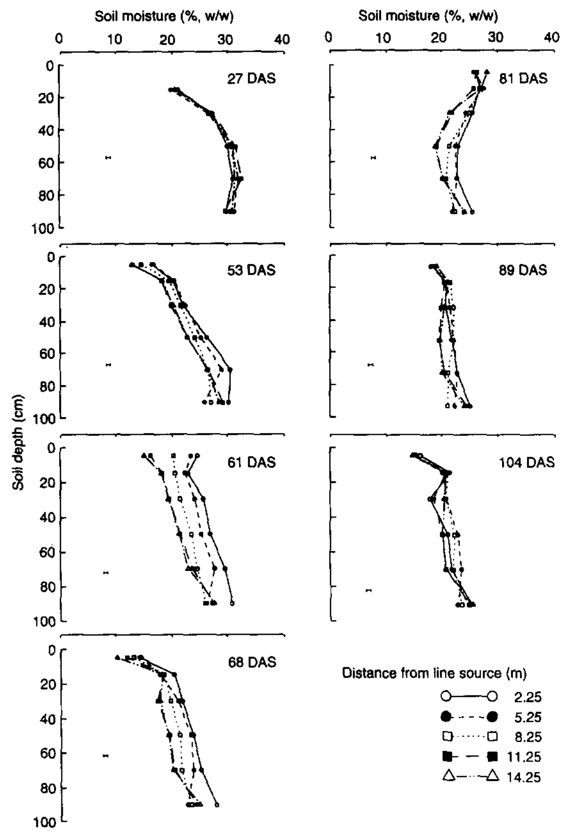

Fig. 1. Soil moisture profiles during the line-source sprinkler experiment in 1985/86. Water was applied by sprinkler at 28 and 53 DAS and 52.2 mm rainfall was received during 75–76 DAS. Bars indicate standard errors of means for soil moisture × depth interaction.

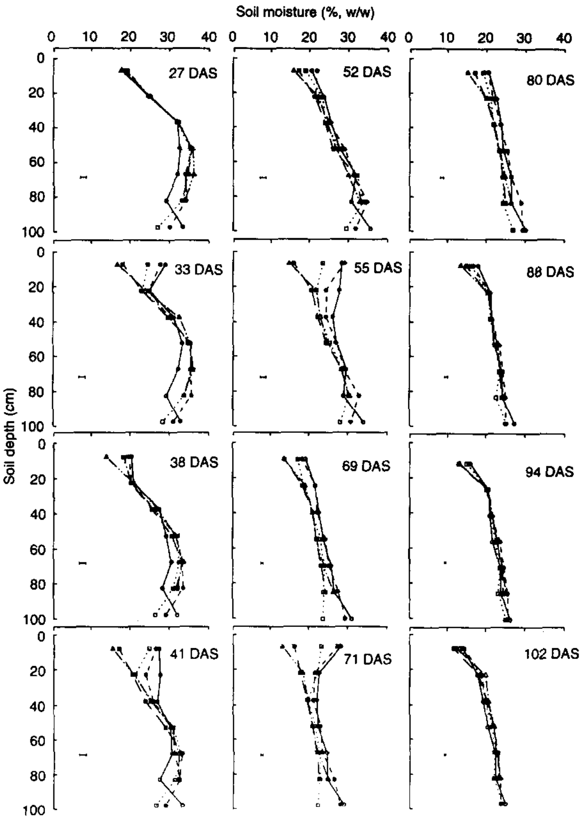

Fig. 2. Soil moisture profiles during the line-source sprinkler experiment in 1986/87. Water was applied by sprinklers at 31, 39, 53 and 69 DAS. Bars indicate standard errors of means for soil moisture × depth interaction.

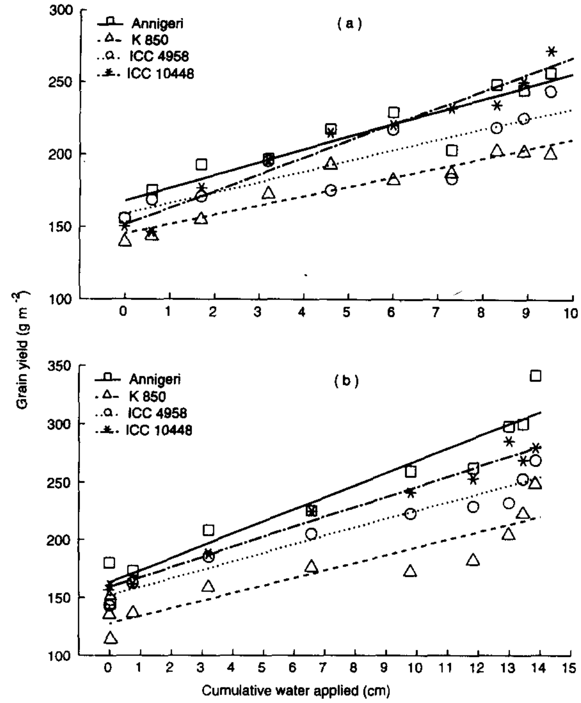

Fig. 3. Response of grain yield of four control cultivars to water applied by line-source sprinklers in Vertisols at ICRISAT Center in 1985/86 (a) and 1986/87 (b).

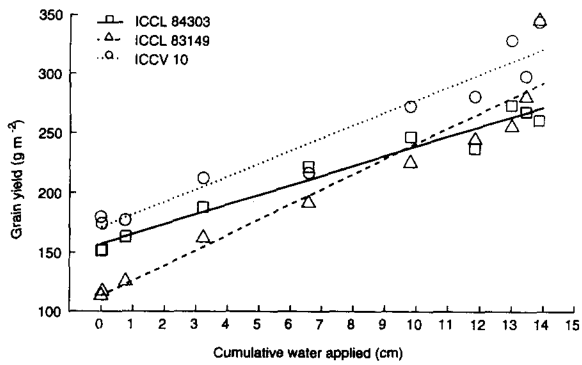

Fig. 4. Response of grain yield of some test lines to water applied by line-source sprinklers in Vertisol at ICRISAT Center in 1986/87.

10985, which are drought susceptible; and K 850, of medium duration. Other entries were recently developed breeding lines at ICRISAT.

To measure water applied by sprinklers, rows of plastic buckets were placed at 1.5-m intervals extending from the line-source. Four rows of buckets were placed in each block, two in line with sprinkler heads and two between them. Neutron access tubes were installed at 3-m intervals in dummy plots, sown to ICCC 33 in 1985/86 and Annigeri in 1986/87, in each block. Neutron moisture meter (Depth Moisture Gauge, Model 3332, Troxler Electronic Laboratories, Inc., NC, USA) readings at various soil depths were made on 7 occasions in 1985/86 and 12 in 1986/87 (Figs. 1 and 2). Moisture content in the surface soil (0–10 and 10–20 cm in 1985/86 and 0–15 and 15–30 cm in 1986/87) was measured gravimetrically.

In the first season, two seeds per hill were sown on 30 October 1985. Seeds were treated with Thiram, and a slurry of *Rhizobium* strain IC 76 peat-based inoculum was applied in each row. A post-sowing irrigation, by perfo-pipe sprinkling evenly across the experimental area, was given on 1 November 1985, considered the effective date of sowing. Seedlings emerged a week later and were thinned to the required spacing at 15

Table 1
Comparison of moisture response of some entries under line-source sprinklers in 1985/86 as measured by components of linear regressions of plant biomass and yield on water applied

Entry	Aerial biomass			Grain yield		
	Intercept ($g\ m^{-2}$)	Slope ($g\ g^{-1}\ m^{-2}$)	r^2 (%)	Intercept ($g\ m^{-2}$)	Slope ($g\ g^{-1}\ m^{-2}$)	r^2 (%)
Annigeri	294.6±10.50	16.1±1.74	90.3	168.2±7.40	8.9±1.23	85.0
ICCL 83228	302.2±9.52	12.5±1.58	87.2	167.0±6.52	8.8±1.08	87.8
ICC 4958	280.2±15.10	17.1±2.51	83.5	159.1±8.55	7.4±1.42	74.2
ICCL 83135	281.8±13.50	14.8±2.24	82.5	154.7±7.78	8.0±1.29	80.7
ICC 10448	259.4±10.20	20.2±1.70	94.0	151.3±5.11	11.7±0.85	95.4
ICCL 84225	272.6±7.19	15.5±1.19	94.9	149.4±4.28	10.2±0.71	95.8
ICCL 83149	251.5±7.92	16.1±1.32	94.3	148.3±6.14	8.6±1.02	88.6
K 850	284.3±7.17	13.6±1.19	93.5	145.2±4.58	6.6±0.76	89.1
ICCL 82115	289.6±10.10	13.7±1.67	88.0	144.4±6.62	8.1±1.10	85.4
ICCL 83132	261.1±6.27	17.5±1.04	96.9	138.0±4.68	9.2±0.78	93.9
ICCL 82108	259.7±10.90	14.3±1.81	87.2	136.4±4.59	7.9±0.76	92.3
ICCL 84328	254.1±12.80	16.1±2.13	86.2	134.4±5.24	9.6±0.87	93.0
ICCL 82230	224.2±10.20	18.7±1.70	93.0	130.8±7.66	9.2±1.27	85.0
ICC 11051	241.3±7.06	16.5±1.17	95.6	129.0±4.70	8.7±0.78	93.2
ICCL 84224	279.1±7.49	15.6±1.24	94.6	128.7±4.75	9.6±0.79	94.2
ICCL 83224[a]	246.3±9.28	9.9±1.54	81.8	128.1±8.18	3.5±1.36	37.9
ICCL 84325	240.1±4.00	11.0±0.67	96.8	124.5±3.13	5.9±0.52	93.4
ICCC 33	284.1±8.83	13.3±1.47	90.1	120.4±4.29	7.3±0.71	92.0
ICCL 81215	243.0±14.00	16.8±2.33	84.9	119.5±7.29	9.0±1.21	85.8
ICC 10985[a]	207.1±10.30	6.9±1.71	62.7	112.5±5.99	2.0±1.00	26.3
ICCL 84219[a]	223.3±7.17	6.9±1.19	78.2	111.1±2.89	−0.2±0.48	0.0

[a]Disease-affected.

days after sowing (DAS). Plots were regularly hand-weeded.

In the second season, single seeds were drilled on 28 October 1986 at 5-cm within-row spacing and later (14–20 DAS) thinned to 10 cm. Post-sowing perfo-pipe irrigation was given on 31 October. Seeds were treated with Benlate T at 0.5% but no *Rhizobium* was applied as rhizobial inoculation responses were not obtained in this field (data not shown).

Line-source sprinkler applications after sunset when windspeed was $<3\ km\ h^{-1}$ were made in 1985/86 on 29 November (28 DAS) and 23 December (53 DAS) and in 1986/87 on 1 December (31 DAS), 9 December (39 DAS), 23 December (53 DAS) and 8 January (69 DAS).

Intensive protection against *Helicoverpa armigera* (pod borer) was provided by regularly spraying endosulphan at $0.7\ kg\ ha^{-1}$.

At harvest on 14 February 1986, plants from four 0.8-m rows on each bed were harvested separately, so as to give 10 sectors (plot representing one water deficit treatment across the gradient) per plot. In the next season, at harvest on 12 February 1987, 4 rows of each entry in 1.5-m sectors were harvested. Grain yield and aerial biomass were estimated for each sector. To assess moisture response, these parameters were regressed against total water applied sector-wise.

3. Results

During the crop growth period, in 1985/86, rain was recorded on 15/16 December (8.1 mm) and 14/15 January (52.2 mm); in 1986/87 on 1 November (3.8 mm), 8 November (32.2 mm), 27/28 December (6.0 mm) and 11 January (4.4 mm) with traces on 31 October, 4/5 November and 15 December. Total amounts of water applied along the line-source gradient are indicated in Figs. 3 and 4.

Water supply during the crop growth period, either

Table 2
Comparison of moisture response of some entries under line-source sprinklers in 1986/87 as measured by components of linear regressions of plant biomass and yield on water applied

Entry	Aerial biomass			Grain yield		
	Intercept ($g\ m^{-2}$)	Slope ($g\ g^{-1}\ m^{-2}$)	r^2 (%)	Intercept ($g\ m^{-2}$)	Slope ($g\ g^{-1}\ m^{-2}$)	r^2 (%)
ICCV 10	312.9±15.20	23.1±1.67	95.5	170.9±8.73	10.7±0.96	93.3
Annigeri	283.6±16.10	21.4±1.77	94.2	163.2±9.47	10.6±1.04	91.9
ICC 10448	262.5±7.94	19.2±0.87	98.2	159.0±3.73	8.7±0.41	98.1
ICCL 84303	273.7±10.70	20.5±1.17	97.1	157.3±5.07	8.2±0.56	96.0
ICCL 85210[a]	264.5±8.18	12.2±0.90	95.4	152.6±7.56	0.6±0.83	0.0
ICCL 85225	272.0±13.80	24.0±1.51	96.5	152.5±4.27	10.2±0.47	98.1
ICC 4958	256.3±11.70	21.2±1.28	96.8	152.0±5.22	7.4±0.57	94.8
ICCV 17	263.7±14.70	29.0±1.61	97.3	151.8±4.56	10.0±0.50	97.8
ICCL 84223	265.8±10.20	25.4±1.12	98.3	151.6±5.81	11.3±0.64	97.2
ICCL 85211[a]	267.9±12.90	12.3±1.41	89.3	150.7±7.45	2.0±0.82	37.1
ICCV 8	272.3±21.40	20.2±2.35	89.0	150.6±8.34	8.5±0.91	90.5
ICCL 84205	258.9±7.42	21.4±0.81	98.7	147.1±3.52	8.8±0.39	98.3
ICCC 37	265.4±18.20	23.8±2.00	94.0	146.5±6.65	10.9±0.73	96.1
ICCL 85307	241.0±9.86	18.2±1.08	96.9	143.6±6.36	8.8±0.70	94.6
ICCL 84311	234.9±12.30	18.1±1.35	95.2	141.4±4.04	9.4±0.44	98.1
ICCL 83227	252.6±14.40	20.2±1.58	94.7	140.0±8.40	9.7±0.92	92.4
ICCC 42	247.7±6.94	19.9±0.76	98.7	136.8±3.39	9.3±0.37	98.6
ICCL 84204	228.9±21.00	25.1±2.31	92.8	130.0±4.37	12.0±0.48	98.6
ICCL 82104	234.4±7.21	22.2±0.79	98.9	129.8±5.01	10.2±0.55	97.4
ICCC 38	235.7±7.44	21.2±0.82	98.7	127.4±4.37	9.4±0.48	97.7
K 850[a]	247.4±18.80	18.6±2.07	89.9	127.3±8.93	6.6±0.98	83.2
ICCL 83228	216.7±7.22	20.5±0.79	98.7	125.3±3.16	11.8±0.35	99.2
ICCL 84215	283.2±14.50	22.2±1.59	95.5	124.5±8.57	9.9±0.94	92.4
ICC 8346	270.5±9.08	21.2±1.00	98.0	123.0±4.76	8.0±0.52	96.3
ICCL 84327	240.5±4.30	21.4±0.47	99.6	122.5±3.68	9.6±0.40	98.4
ICCL 85310	244.3±21.00	21.2±2.31	90.3	118.0±8.44	10.6±0.93	93.5
ICCL 85333	226.6±24.10	23.1±2.64	89.4	117.4±12.10	10.8±1.33	87.7
ICCL 82230	194.5±23.20	24.8±2.54	91.3	115.5±6.53	10.1±0.72	95.7
ICCV 9	221.9±14.30	23.0±1.57	96.0	115.2±3.63	11.2±0.40	98.9
ICCC 43	225.5±13.80	22.0±1.52	95.9	114.9±5.63	9.6±0.62	96.4
ICCC 47	205.5±15.20	22.9±1.67	95.4	114.0±5.96	10.1±0.65	96.4
ICCL 83149	200.1±27.10	25.1±2.97	88.7	113.3±12.10	12.8±1.33	91.1
ICCC 36	205.8±11.50	20.1±1.26	96.6	112.6±4.15	9.2±0.46	97.8
ICCC 32	254.5±14.30	22.8±1.57	95.9	110.4±4.22	9.2±0.46	97.8
ICCL 83224[a]	208.1±8.08	9.2±0.89	92.3	109.2±8.47	1.4±0.93	13.4
ICCL 85311	205.0±11.60	20.0±1.27	96.5	108.5±5.43	10.6±0.60	97.2
ICCV 3	176.9±14.10	16.6±1.55	92.7	107.2±7.81	8.8±0.86	92.0
ICCV 4	200.1±17.20	23.5±1.88	94.5	105.1±7.68	10.9±0.84	94.8
ICCV 5	203.9±16.90	24.1±1.85	94.9	104.3±4.88	10.9±0.53	97.9
ICC 11051[a]	186.1±13.60	16.6±1.49	93.2	102.8±6.79	7.3±0.74	91.4
ICCL 85314	214.1±11.70	20.3±1.29	96.5	101.3±3.68	9.2±0.40	98.3
ICCC 34[a]	222.2±14.50	10.9±1.59	83.8	93.3±6.52	2.7±0.72	59.1
ICCV 2	170.8±12.40	17.0±1.36	94.5	88.3±5.55	7.9±0.61	94.8
ICCL 85325	232.2±9.57	17.4±1.05	96.8	87.6±3.42	6.9±0.38	97.4
ICC 10985[a]	164.4±7.98	9.1±0.88	92.2	86.4±2.58	1.9±0.28	83.2
ICCL 84219[a]	155.1±11.40	−1.9±1.25	12.8	65.9±5.17	−3.4±0.57	79.7

[a]Disease-affected.

Table 3
Grouping of entries into stable (high intercept, high slope), drought-resistant (high intercept, low slope), drought-susceptible (low intercept, high slope) and poor performers (low intercept, low slope) categories based on line-source sprinkler responses on grain yield. High intercept is taken as > 150 and high slope as > 9.0 in 1985/86 and > 10.0 in 1986/87

Season	Category			
	Stable	Drought resistant	Drought susceptible	Poor performers
1985/86	Annigeri	ICC 4958	ICCL 81215	K 850
	ICC 10448		ICCL 82230	ICC 10985
	ICCL 83228		ICCL 83132	ICC 11051
	ICCL 84225		ICCL 84224	ICCL 82108
			ICCL 84328	ICCL 82115
				ICCL 83135
				ICCL 83149
				ICCL 83224
				ICCL 84219
				ICCL 84325
1986/87	Annigeri[a]	ICC 4958[a]	ICCC 37	K 850[a]
	ICCV 10	ICC 10448[a]	ICCC 47	ICC 8346
	ICCV 17	ICCV 8	ICCV 4	ICC 10985[a]
	ICCL 84223	ICCL 84303	ICCV 5	ICC 11051[a]
	ICCL 85225		ICCV 9	ICCC 32
			ICCL 82104	ICCC 34
			ICCL 82230[a]	ICCC 36
			ICCL 83149	ICCC 38
			ICCL 84204	ICCC 42
			ICCL 85310	ICCC 43
			ICCL 85311	ICCV 2
			ICCL 85333	ICCV 3
				ICCL 83224[a]
				ICCL 83227
				ICCL 83228
				ICCL 84205
				ICCL 84215
				ICCL 84219[a]
				ICCL 84311
				ICCL 84327
				ICCL 85210
				ICCL 85211
				ICCL 85307
				ICCL 85314
				ICCL 85325

[a]Repeated from 1985/86.

by irrigation or rainfall, affected moisture content only in the top 30 to 40 cm (Figs. 1 and 2).

Increasing drought stress, with distance from the line-source, accelerated both flowering and maturity of all entries in both seasons. In 1985/86, mean time of 50% flowering was 47 ± 0.2 DAS in the plots closest to the line source compared to 43 ± 0.2 DAS in the farthest; in 1986/87 these values were 46 ± 0.4 and 41 ± 0.4, respectively. Mean time to maturity of the entries was 97 ± 0.2 DAS in wet plots compared to 94 ± 0.2 DAS in dry plots in the 1985/86 season and in the 1986/87 season 96 ± 0.8 DAS and 83 ± 0.8 DAS, respectively.

Provided plants were not affected by disease, linear relationships between aerial biomass or grain yield and moisture applied were obtained (Tables 1 and 2, Figs. 3 and 4); fitting curvi linear relationships did not significantly improve the coefficient of determination (r^2). For most lines, harvest index remained constant across the moisture gradient, as indicated by slopes of grain yield and aerial biomass (Tables 1 and 2). Thus differences among entries in moisture response could be compared on the basis of linear regression parameters.

For the purpose of comparison, lines having a high intercept value and low slope are considered drought resistant. Those with low intercept and high slope are considered susceptible to drought but responsive to irrigation. Lines having a high intercept and also high slope, are considered relatively stable across the given moisture gradient. Critical values for intercept were chosen as 150 g m^{-2} grain yield in both seasons and for slope they were set at 9.0 in 1985/86 and 10.0 in 1986/87. These values were chosen on the basis of the approximate mean values of the controls.

Annigeri showed a stable response in grain yield in both years (Tables 1 and 2, Fig. 3). The previously identified drought-resistant cultivar ICC 4958 showed a similar drought-resistant response in the present studies (Fig. 3).

Representative test lines showing stable, drought-resistant and drought-susceptible responses in 1986/87 are shown in Fig. 4. Lines falling into these categories are summarized in Table 3. Few of the test lines could be ranked as drought resistant or stable, in comparison with ICC 4958 or Annigeri, respectively.

4. Discussion

The soil moisture data (Figs. 1 and 2) indicate that the responses of chickpea growth and yield to irrigation were due to soil moisture changes in the 0–40 cm soil profile, as soil moisture at greater depths was hardly affected by irrigation or rainfall. Thus chickpea lines responsive to moisture application in the postrainy season in this environment would probably have greater relative water uptake capability in the upper soil layers than the drought-resistant ones.

The linear responses of chickpea biomass and yield to applied water suggest that use of a line-source system to characterize genetically based differences in moisture response would be unnecessary in this environment. Two points, as obtained in treatments with and without irrigation, are sufficient to determine intercept and slope, provided mean yields between these two points differ markedly. This has also been found for pearl millet grown in Alfisols at this location (Mahalakshmi et al., 1990). However, greater accuracy may be expected with more than two moisture treatment levels. For screening large numbers of entries, either germplasm or advanced generation breeding material, these results suggest that two widely separated soil moisture levels are sufficient to distinguish response to soil moisture over the soil moisture ranges covered in these studies. Use of this alternate method might to some extent reduce the precision and accuracy of the experiment but will require considerably less resources of labour, equipment and land.

Even at high soil moisture levels, near the sprinkler line, plants did not lodge and harvest index remained constant. In sub-tropical environments such as in northern India, excessive moisture conditions result in lodging and reduced harvest indices (Saxena, 1984). Thus over-irrigation is a major concern in such environments. The constancy of harvest index with increasing moisture in our tropical environment may be a consequence of the shorter growth duration and the more rapid depletion of soil moisture by evapotranspiration. This suggests that high yield levels can be obtained and are more assured in the peninsular Indian environment if adequate surface soil moisture levels are maintained (Saxena and Johansen, 1990a).

The performance of Annigeri and the drought-resistant controls, except perhaps for ICC 10448 in 1985/86, is consistent with previous findings (Saxena, 1987). The yields without water application are high, even considering that they are estimated from small plots, indicating only moderate levels of drought stress. If the curves are extrapolated to lower soil moisture levels, the yields of the drought-resistant lines would exceed that of Annigeri. Generally, similar responses were obtained in both seasons for common entries despite weather differences between seasons, particularly the heavy rainfall in January 1986 (Tables 1, 2 and 3), suggesting true genotypic differences in response. The number of lines in the poorly performing group are many. The similar response of these lines between the two years makes it possible for the breeders to confidently discard them on the basis of their not

Table 4
Grand mean seed yields and coefficients of variation calculated separately for nonirrigated (NI) and irrigated (I) main-plot treatments of split plot experiments testing response of several chickpea lines (in sub-plots) to irrigation during the 1985/86 to 1990/91 seasons at ICRISAT Center. Methodology as described in Saxena (1987). Mostly unpublished data of Crop Physiology Unit, Legumes Program, ICRISAT

Season	Soil type	Mean seed yield (kg ha^{-1})		Coefficient of variation (%)	
		NI	I	NI	I
1985/86	Vertisol	912	1522	13.6	14.1
	Alfisol	700	1181	12.6	17.2
1986/87	Vertisol	700	1922	12.3	10.5
	Vertisol	1242	2123	18.9	10.1
1987/88	Vertisol	1581	2066	7.1	4.3
	Alfisol	933	833	8.6	24.2
1988/89	Vertisol	596	1677	11.2	13.8
	Vertisol	630	1777	10.4	9.6
	Alfisol	800	1517	17.4	10.6
1989/90	Vertisol	1293	1738	13.4	13.5
	Vertisol	1040	1321	12.7	20.3
	Alfisol	523	924	19.6	19.8
1990/91	Alfisol	818	1156	13.6	15.7

being useful for either drought-prone or adequately irrigated environments.

Although chickpea breeding efforts have been aimed at high and stable yields, only a few breeders' lines (e.g. ICCV 10) could match the response of the long-standing locally-adapted control Annigeri (Table 3). Similarly, few drought-resistant lines could be identified. Most lines were drought susceptible, showing varying degrees of responsiveness to irrigation (Tables 1, 2 and 3). An explanation for this behaviour may lie in the soil moisture regimes under which selections in the ICRISAT breeding program have been carried out. The F_2 and F_3 generations are normally grown in disease-screening nurseries under irrigation. The F_4 to F_7 generations, from which initial selections for yield potential are made, are grown on no more than an establishment irrigation. Subsequent generations, in preliminary and advanced yield trials, are grown both with irrigation and without (apart from an establishment irrigation if the facility is available). Advanced selections are then made on the basis of good performance in both environments. This approach favors yield stability across a range of moisture environments but may not lead to yield optimization in any given narrow range of available soil moisture. It is likely that opposing traits are required for good performance under drought and well-watered conditions (Saxena and Johansen, 1990b). Greater partitioning to roots, to enhance drought resistance at the expense of grain yield potential, is one example. Intersection of many of the response curves determined in the present study suggests that genotypic differences are large enough to select lines best suited to particular soil moisture regimes.

The range of water-limited yields can be very wide in this environment, from 0.5 t ha^{-1} on residual soil moisture alone to 3.0 t ha^{-1} in well-irrigated plots (Saxena and Johansen, 1990a). Most chickpea production on Vertisols in peninsular India relies on residual soil moisture, although production from irrigated chickpea is increasing (e.g. in Maharashtra State; R.B. Deshmukh, Rahuri, pers. commun.). The present results suggest the need for separate selection programs for specific target soil moisture environments. At least there should be a separate program for the rainfed (e.g.

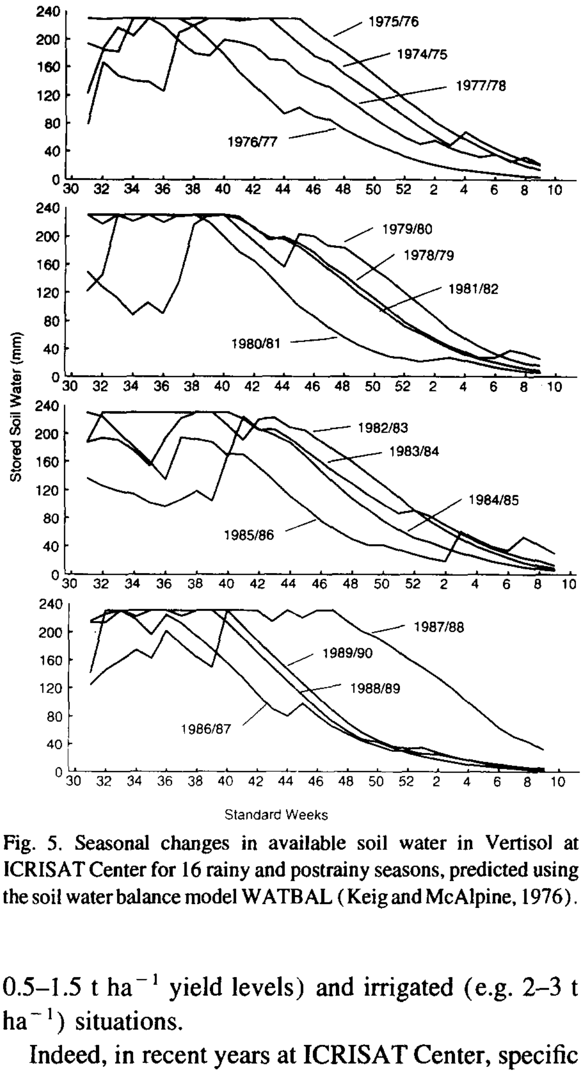

Fig. 5. Seasonal changes in available soil water in Vertisol at ICRISAT Center for 16 rainy and postrainy seasons, predicted using the soil water balance model WATBAL (Keig and McAlpine, 1976).

0.5–1.5 t ha^{-1} yield levels) and irrigated (e.g. 2–3 t ha^{-1}) situations.

Indeed, in recent years at ICRISAT Center, specific selection for highest yield under only rainfed conditions from early generations onward has been in progress, but genetic advance associated with this procedure is yet to be evaluated. Nevertheless, in order to maintain a degree of wider adaptation, best selections in either extreme environment could be further selected for at least moderate performance in the opposite environment. For example, it would be desirable that material selected for typical receding soil moisture conditions would favorably respond to above-average rainfall during the growing period. Specific breeding programs for given soil moisture situations would allow more directed use of parents carrying traits best suited to the situation, realizing that such traits may be deterimental in contrasting soil moisture situations (Saxena and Johansen, 1990b).

Plant breeders are less optimistic about undertaking breeding programs in droughted environments alone, because of large environmental components of variation associated with such environments within and across seasons. This is certainly the case for intermittent drought stress experienced by rainy season crops. However, for postrainy season crops growing on residual soil moisture in soils of high moisture-holding capacity this may not necessarily be the case because comparisons of coefficients of variation in either rainfed or irrigated treatments at ICRISAT Center indicate no consistently greater variation under rainfed conditions (Table 4). Fig. 5 shows available soil moisture patterns for the postrainy season on Vertisols at ICRISAT Center from 1974/75 to 1989/90 as calculated by the soil water balance model WATBAL (Keig and McAlpine, 1976). Soil moisture depletion patterns are similar in most years when the soil profile is charged by mid-October. An exception was 1987/88 when heavy rains in October/November displaced the depletion curve by about one month. The other exceptions occurred when the soil profile was not charged in the rainy season and the depletion curve was displaced in the opposite direction. This situation could be remedied, to produce average-year soil moisture depletion curves, by irrigating the soil to field capacity before sowing in years with below-average rainy season rainfall. In any case an establishment irrigation is recommended to ensure an even plant stand, to separate effects of terminal drought stress from possible stress at the seedling stage. Thus, except when heavy rains extend beyond the end of the normal rainy season, consistent and reproducible soil moisture environments can be obtained.

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