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An analysis of yield variation among long-duration pigeonpea genotypes in relation to season, irrigation and plant population

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SUMMARY

The response of eight long-duration pigeonpea [*Cajanus cajan* (*L*) Millsp.] genotypes to irrigation was studied at Gwalior in Central India during the 1990–91, 1991–92 and 1992–93 growing seasons on an Inceptisol. The crop was grown at two spacings as it was expected that crop density could interact with the crop's ability to extract soil moisture. The irrigation treatment received furrow irrigation four times during the 1990–91 and 1992–93 seasons and twice during the 1991–92 season. Grain yields of all genotypes were 11% higher when planted at higher density than at low density. There was a differential variation in yield and harvest index among genotypes due to season but not due to spacing and irrigation suggesting the validity of the present approach of testing genotypes under optimum conditions. Grain yield declined by 21% from the 1990 to 1992 season. The decline was > 1 t/ha in some cultivars (ICPL 366, GW3), and between 0·5 and 1·0 t/ha in others (NP [WR] 15, ICP 87143 and ICPL 84072). In others (Bahar, ICP 9174, ICP 8860) the yield fluctuation was < 0·5 t/ha. The genotypes' mean yields were as high as 2·7 t/ha for ICPL 87143, ICPL 84072 and ICPL 366. There was a significant reduction in both grain yield (16%), and also above-ground plant dry mass (18%) due to soil moisture limitation in the unirrigated treatment. Both the above-ground plant dry mass and grain yields were significantly more at high plant density than at lower plant density especially with irrigation. The genotypes were found to differ in their response to production environment (irrigation, spacing and to the undefined differences of the 3 years). Genotypic variation in yield within a production environment was found to vary in relation to changes in harvest index and across environment (irrigation, seasons) due to variation in total dry matter production. A lack of negative relationship between the total dry matter and harvest index suggests the possibility of optimizing both for obtaining higher yield from long-duration genotypes.

INTRODUCTION

Pigeonpea is an important grain legume of the semi-arid tropics. The variation in time to maturity of pigeonpea [*Cajanus cajan* (*L*) Millsp.] is an important factor in the crop's adaptation to diverse agroclimatic areas and agronomic systems. Medium- (151–180 days) and long-duration (about 220 days) landraces of this crop contribute to the bulk of production both in India (Ali 1990) and other major pigeonpea growing countries (Singh 1991). Hence overcoming constraints that affect the productivity of these should constitute a central strategy for their improvement. In traditional cropping systems, the crop is often sown as inter-cropped or mixed with other crops at the beginning of the rainy season. Its reproductive growth occurs on residual moisture left after the companion crop is harvested (Ali 1990). In medium-duration pigeonpea which is largely grown in peninsular India, lack of moisture during the reproductive phase (terminal drought stress) reduced yield from the potential yield of 1760 kg/ha to about 600 kg/ha (Chandra Mohan 1969) and there are considerable genotypic differences in this regard (ICRISAT 1987). It is not known if terminal drought affects the stability of the yield of long-duration genotypes as well and whether some genotypes can endure it better than others. This

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information is necessary for determining research needs in this area. We, therefore, studied the response of several long-duration pigeonpea genotypes to irrigation applied after the normal rainy season, i.e. June–October at Gwalior in central India.

MATERIALS AND METHODS

The trials were conducted during the cropping seasons of 1990–91, 1991–92 and 1992–93 on an Inceptisol (*Typic Ustochrepts*) at the ICRISAT-JNKVV (Jawaharlal Nehru Krishi Viswa Vidyalaya) Cooperative Agricultural Research Station farm at Gwalior (26° N, 78° E). The plant available water-holding capacity of the Inceptisol is about 140 mm to a metre depth. The chemical properties of soil at the experimental site are given in Table 1. The soil of the experimental site was analysed for pH (McLean 1982), electrical conductivity, available and total N (Keeney & Nelson 1982), and available P (Olsen & Sommers 1982). The rainfall and temperatures recorded during the cropping seasons are presented in Fig. 1. Available soil moisture during the 1990 and 1992 seasons (Fig. 2) was estimated using a water balance model (Keig & McAlpine 1974).

The trials were laid out in split-split plot design with three replications. The rainfed and supplemental irrigation treatments during the post-rainy season were assigned to main plots. Eight pigeonpea genotypes [ICPL 366, ICPL 87143, ICP 8860, NP(WR) 15, ICP 9174, ICPL 84072, Gwalior 3 and Bahar] were assigned to subplots and plant spacings (60×40 cm and 120×40 cm) were in sub-subplots. All the genotypes tested are of similar growth habit and phenology and adapted to the agro-ecological conditions prevailing in northern India where long-duration pigeonpeas are traditionally grown. This group includes popular released cultivars (Gwalior 3, NP (WR) 15, Bahar), high yielding advanced breeding lines (ICPL 366, ICPL 84072, ICPL 87143) and elite germplasm selections (ICP 9174 and ICP 8860). We grew the crop at two plant densities, as it was expected that this factor would affect the plants' ability to extract soil moisture. The sub-subplot size was $4{\cdot}8 \times 4$ m for the 60×40 cm spacing treatment, and 6×4 m for the 120×40 cm spacing treatment. The crop was sown on 5 July 1990, 18 July 1991 and 15 July 1992. A basal dose of 100 kg diammonium phosphate (18 kg N, 16 kg P) per ha was applied. Weeds were controlled by an application of Stomp® (pendimethalin) *c.* 1·5 kg active ingredient per ha before crop emergence. In addition, plots were weeded at about 30 days after sowing (DAS). The crop was protected from eriophyd mites (*Aceria cajani*) which spread sterility mosaic disease and from pod fly (*Melanogromyza obtusa*) by spraying insecticides such as dimethoate and endosulfan. The crop was protected from bird damage during podding time by scaring them away. The irrigated treatment received four irrigations through furrows in 1990/91 (on 5 November, 20 December, 3 and 30 January), two irrigations during 1991–92 (on 26 January and 17 March) and four irrigations during 1992–93 (on 15 November, 12 December, 8 January and 23 February). In 1991–92, two protective irrigations (on 18 September and 29 October) were uniformly given to the trial because of early cessation of monsoon. With each irrigation about 50 mm water was applied. At each irrigation, the amount of water discharged per minute from six different openings of the gated irrigation pipe was collected in a bucket and measured using a measuring cylinder. The rate of discharge per minute was calculated as a mean of six measurements and the duration of irrigation was recorded. The amount of irrigation in mm was calculated by dividing the total quantity of water applied by area irrigated.

Observations on plant height (five plants/plot) at about monthly intervals, days to 50% flowering and days to maturity were recorded during 1990–91 and 1992–93 crop seasons. The grain yield was estimated from a net plot area of about 12 m^2. Total above-ground recoverable oven-dry matter at maturity was estimated by multiplying oven dry weight of a subsample of five plants/plot to the ratio of net plot fresh weight/subsample fresh weight. The extent of pod damage by pod fly was assessed by opening and examining 100 pods/plot for grain damage. The data were analysed using the GENSTAT 5.1 program (1993).

RESULTS

Weather and soil moisture

The total rainfall received during July–March in the 1991/92 and 1992/93 seasons was less than the long-term average rainfall but in 1990–91 it was slightly

Table 1. *Chemical properties of soil at the experiment site during 1990*

Depth (cm)	pH	Electrical conductivity (dS/m^2)	NH_4–N (mg/kg)	NO_3–N (mg/kg)	Available P (mg/kg)	Total N (mg/kg)
0–15	7·97	0·41	3·9	41·0	14·4	621·2
15–30	8·02	0·30	3·4	25·5	9·1	488·6

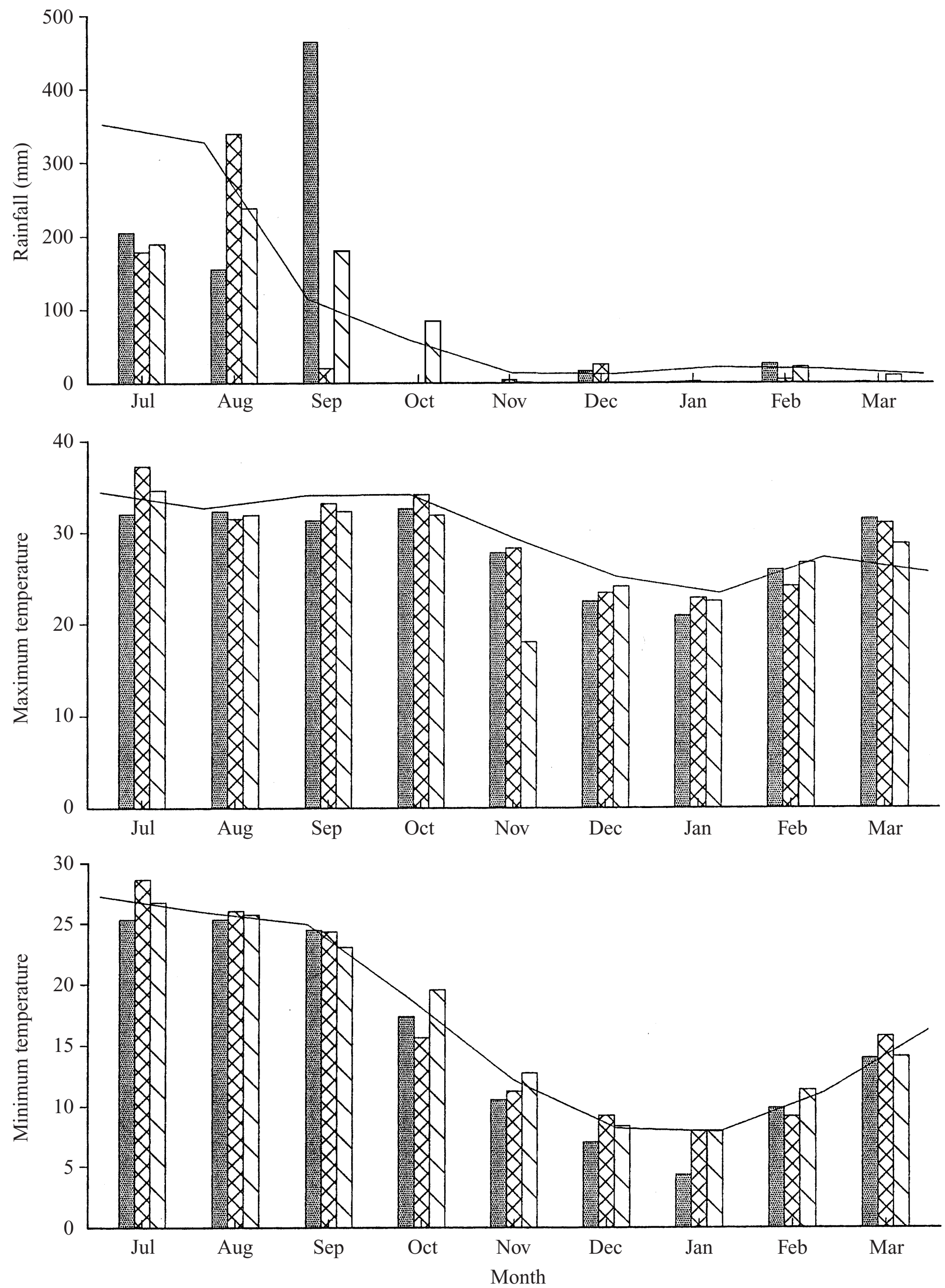

Fig. 1. Rainfall (mm) and average maximum and minimum temperatures (°C) recorded at Gwalior during the crop growth period 1990, 1991 and 1992. ——, long-term mean; ▧, 1990–91; ⊠, 1991–92; ▧, 1992–93.

more (Fig. 1). In 1990–91, the rainfall was less in July–August, and in excess during September compared to the long-term mean. In 1991/92, the rainfall was particularly deficient in September compared to the long-term mean. In 1992/93, the rainfall was reasonably well distributed except from November to January. The minimum and maximum temperatures began to fall from November, and started to increase from March when plants were in the flowering and early podding stages. The plant extractable soil water

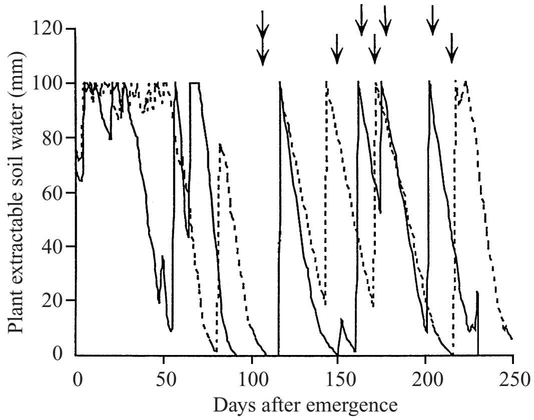

Fig. 2. Simulated variation in plant extractable soil water (PESW) in the profile in irrigated treatments. The arrows indicate the time of irrigation during the crop season (— 1990/91, top arrows; - - - - - - -,1992/93, bottom arrows). The data for PESW during the 1991/92 growing season could not be collected.

increased following irrigation during the post-rainy season and then declined (Fig. 2).

Analysis of variance

Pooled analysis of variance revealed nonsignificant effects of season for total dry matter but a significant ($P = 0{\cdot}05$) effect for yield and harvest index (Table 2). The season × genotype interaction was also significant for grain yield and harvest index. The main effects of the irrigation treatment were significant for total dry matter and grain yield but not for harvest index. The main effect of genotype was significant for grain yield and harvest index but not for total dry matter. The main effect of spacing was significant for total dry matter, grain yield and harvest index. However, for yield the interaction of the spacing treatment was significant only with season. The interactions of season × irrigation × genotype for total dry matter and season × genotype and irrigation × genotype for harvest index were also significant.

For total dry matter, the contribution of seasons sums of squares (SS) to total sums of squares (TSS) was 13·5%; for genotype it was 2·35%, spacing SS 9·7%, and irrigation 7·8%. In contrast, for yield, seasons contributed 16·5% SS, genotypes 9·9% SS, irrigation 8·4%, season × genotype 7·9% and spacing 4·2% to TSS. For harvest index, the contribution of season SS was 13·9% to the TSS. The overall coefficient of variation was 17% for total dry matter, 15% for yield and 17% for harvest index.

Season effects

Grain yield declined by 21% from the 1990 to 1992 season (Table 3). The decline was > 1 t/ha in some cultivars (ICPL 366, GW3), and between 0·5 and

Table 2. *Analysis of variance for response of long-duration pigeonpea to irrigation at Gwalior* (*pooled analysis of 3 years' data*)

Source of variation	DF	Total dry mass SS	Grain yield SS	Harvest index SS
Replication	2	73·6	0·58	52·3
Season	2	467·4	17·6*	996·2*
Residual	6	411·3	5·8	422·2
Irrigation	1	268·8*	8·97*	0·68
Season × Irrigation	2	43·8	1·1	5·86
Residual	6	160·4	4·3	124·9
Genotype	7	81·5	10·6*	480·6**
Season × Genotype	14	81·7	8·4*	866·8**
Irrigation × Genotype	7	70·6	2·3	345·9*
Season × Irrigation × Genotype	14	249·4*	4·9	285·3
Residual	84	737·6	23·7	1720·5
Spacing	1	337·5***	4·5**	238·7**
Season × Spacing	2	15·9	0·93*	37·8
Irrigation × Spacing	1	0·44	0·36	19·8
Genotype × Spacing	7	25·3	0·37	57·1
Season × Irrigation × Spacing	2	12·1	0·67	6·8
Season × Genotype × Spacing	14	86·9	1·57	104·5
Irrigation × Genotype × Spacing	7	40·2	0·76	143·6
Residual	108	392·4	13·4	1346·7
Grand total	287	3464·2	106·5	7163·7

*, $P = 0{\cdot}05$; **, $P = 0{\cdot}01$; ***, $P = 0{\cdot}001$.
SS, sums of squares.

Table 3. *Effect of irrigation and spacing on grain yield (t/ha) of long-duration pigeonpea grown on Inceptisol at Gwalior during 1990–91, 1991–92 and 1992–93*

	1990/91		1991/92		1992/93		Mean	
Genotype	Rainfed*	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated
ICPL 366	2·82	3·49	2·37	2·46	1·71	2·46	2·30	2·80
ICPL 87143	2·85	3·22	2·48	2·63	2·34	2·66	2·56	2·84
ICP 8860	2·02	2·64	2·21	2·59	1·72	2·31	1·98	2·52
NP (WR) 15	2·47	2·27	2·37	2·14	1·60	2·13	2·15	2·18
ICP 9174	2·04	2·77	2·06	2·59	1·88	2·10	1·99	2·49
ICPL 84072	2·49	3·52	2·37	2·75	2·23	2·44	2·36	2·90
Gwalior 3	2·46	2·47	2·50	3·05	1·59	1·60	2·19	2·37
Bahar	2·12	2·98	2·31	2·15	2·11	2·16	2·18	2·43
Mean	2·41	2·92	2·34	2·54	1·90	2·23	2·21	2·57
	1990/91		1991/92		1992/93		Mean	
	60 × 40 cm†	120 × 40 cm	60 × 40 cm	120 × 40 cm	60 × 40 cm	120 × 40 cm	60 × 40 cm	120 × 40 cm
ICPL 366	3·37	2·94	2·51	2·32	2·15	2·02	2·67	2·43
ICPL 87143	3·11	2·96	2·85	2·26	2·50	2·50	2·82	2·57
ICP 8860	2·42	2·24	2·62	2·19	2·06	1·97	2·37	2·13
NP (WR) 15	2·37	2·37	2·33	2·18	1·97	1·76	2·22	2·10
ICP 9174	2·60	2·21	2·58	2·07	1·90	2·08	2·36	2·12
ICPL 84072	2·97	3·04	2·72	2·39	2·51	2·17	2·73	2·53
Gwalior 3	2·60	2·33	2·99	2·55	1·78	1·42	2·46	2·10
Bahar	2·69	2·41	2·54	1·93	2·22	2·05	2·48	2·13
Mean	2·77	2·56	2·64	2·24	2·14	2·00	2·51	2·26

S.E. ± 0·070 (irrigation), 0·089 (genotype), 0·030 (spacing), 0·176 (season × genotype) except when comparing means with same level of season 0·154, 0·107 (season × spacing) except when comparing means with same level of season 0·051.
CV (%) 14·9
*, Mean of 60 × 40 cm and 120 × 40 cm spacings; †, Mean of rainfed and irrigated treatments.

1·0 t/ha in some cultivars (NP [WR] 15, ICP 87143 and ICPL 84072). In others (Bahar, ICP 9174, ICP 8860) the yield fluctuation was < 0·5 t/ha.

Irrigation and spacing effects

Irrigation increased the yield in ICPL 366, ICP 9174, ICP 84072 and ICP 8860. In NP (WR) 15 nearly similar yield over 3 years was obtained in the irrigated and the rainfed treatment.

Planting at a high density of four plants/m^2 produced higher yields than at a low density of two plants/m^2, the response being significant in 1991 and 1992 (Table 3).

Genotypic performance

Among the genotypes, the mean yield for three seasons was the largest (2·70 t/ha) in ICPL 87143 followed closely by ICPL 84072 and ICPL 366 (Table 3). The yields of these genotypes were significantly more than the yield of the other five genotypes — GW 3, Bahar, NP(WR) 15, ICP 9174 and ICP 8860. GW 3 produced maximum dry matter and ICPL 9174 lowest, the differences among the genotypes, however, were not significant (Table 4). Harvest index was highest in ICPL 87143 and lowest in GW3, with differences being significant (Table 5). All the genotypes flowered between 164 to 169 days.

Genotype × environment interactions

An analysis of G × E interactions for yield, total dry matter and harvest index was also done treating the combination of three seasons (S1, S2, S3), two irrigations (I, NI) and two spacings (P1 and P2) treatments as 12 agronomic-climatic environments (S1IP1, S1NIP1, S2IP1, S2NIP1, S3IP1, S3NIP1, S1IP2, S1NIP2, S2IP2, S2NIP2, S3IP2 and S3NIP2). The interactions between these environments and genotypes were not significant for yield, total dry matter and harvest index (data not shown).

Relationship of yield with total dry matter and harvest index

Across all the 12 environments and all the eight genotypes the correlation of yield with total dry

Table 4. *Effect of irrigation and spacing (cm) on total above ground dry matter (t/ha) of long-duration pigeonpea genotypes grown on Inceptisol at Gwalior during 1990–91, 1991–92 and 1992–93*

	1990/91		1991/92		1992/93		Mean	
Genotype	Rainfed*	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated
ICPL 366	12·2	15·8	11·0	12·0	8·2	13·2	10·5	13·7
ICPL 87143	13·6	14·6	9·8	11·2	11·7	10·9	11·7	12·2
ICP 8860	11·9	14·8	9·7	11·3	10·4	13·7	10·7	13·3
NP (WR) 15	12·5	13·0	11·5	9·8	6·6	12·9	10·2	11·9
ICP 9174	11·7	14·0	8·1	10·8	9·5	11·3	9·8	12·0
ICPL 84072	11·5	16·7	11·4	12·0	12·4	9·7	11·8	12·8
Gwalior 3	13·2	16·1	9·4	13·2	10·0	13·1	10·9	14·1
Bahar	10·8	15·0	10·9	8·9	12·2	12·9	11·3	12·3
Mean	12·2	15·0	10·2	11·1	10·1	12·2	10·9	12·8
	1990/91		1991/92		1992/93		Mean	
	60 × 40 cm†	120 × 40 cm	60 × 40 cm	120 × 40 cm	60 × 40 cm	120 × 40 cm	60 × 40 cm	120 × 40 cm
ICPL 366	15·2	12·9	12·6	10·5	11·8	9·7	13·2	11·0
ICPL 87143	14·3	13·8	12·4	8·7	11·2	11·5	12·6	11·3
ICP 8860	14·5	12·3	11·9	9·1	13·0	11·0	13·1	10·8
NP (WR) 15	13·0	12·5	11·8	9·5	11·3	8·1	12·0	10·0
ICP 9174	13·9	11·7	11·0	7·9	10·0	10·8	11·7	10·1
ICPL 84072	14·5	13·8	12·9	10·5	12·9	9·1	13·4	11·1
Gwalior 3	15·7	13·6	12·2	10·4	13·2	10·0	13·7	11·3
Bahar	13·9	12·0	11·3	8·3	15·2	9·8	13·5	10·1
Mean	14·4	12·8	12·0	9·4	12·3	10·0	12·9	10·7

S.E. ± 0·43 (irrigation), 0·16 (spacing), 1·51 (season × irrigation × genotype) except when comparing same level of 1·36 (season), 1·21 (season × irrigation), 1·36 (season × genotype).
CV (%) 16·1
*, Mean of 60 × 40 cm and 120 × 40 cm spacings; †, Mean of rainfed and irrigated treatments.

matter was 0·774** ($n = 20$), and with harvest index it was 0·126 (**, $P = 0·01$; ***, $P = 0·001$). However, the separate analysis across genotypes indicated no relationship of total dry matter and yield ($r = 0·522$, $n = 8$) but across the environments this relationship was highly significant ($r = 0·822$***, $n = 12$) (Fig. 3). The opposite was true for the relationship of yield with harvest index which was not significant across environments ($r = 0·045$, $n = 12$) but highly significant across genotypes ($r = 0·871$**, $n = 8$). The relationship between total dry matter and harvest index was not significant across genotypes ($r = 0·065$, $n = 8$) and environments ($-0·590$, $n = 12$). The relationship of rainfed yield and irrigated yield across genotypes over three seasons was also highly significant ($r = 0·63$**, $n = 8$).

DISCUSSION

Long-duration pigeonpeas have been largely used in subsistence agriculture. Since the purpose of this type of cultivation has been to meet the domestic need with little market surpluses of grain, there has been little innovation in its cultivation. Farmers continue to grow its traditional landraces at low plant populations (Mukherjee 1960; Pathak 1970). The results of the study show marked improvement in yield by closer planting (four plants *v.* two plants/m^2) although te responses varied across seasons. The responses to denser planting suggest that the plasticity of these pigeonpeas is limited and about 11% yield gain could be realized by doubling the seed rate. Though it is not substantial in terms of per cent increase, the yield gain of about 250 kg grain for an input of about 2 kg additional seed is economically substantial. Higher planting density would ensure greater stability against losses in plant stand caused by *Fusarium* wilt or waterlogging and increased yield of stems for fuelwood.

Irrigation increased mean yield by 16% thus indicating that terminal drought affects LDP. Similar responses to applied irrigation have been reported in long-duration pigeonpea grown on Vertisol in Rajasthan (Singh *et al.* 1992). However, it may not be economical to apply irrigation to overcome terminal drought for long-duration pigeonpea. A slight reduction in duration may also not provide an effective solution as the crop may flower at low temperatures

Table 5. *Effect of irrigation and spacing (cm) on harvest index (%) of long-duration pigeonpea genotypes grown on Inceptisol at Gwalior during 1990–91, 1991–92 and 1992–93*

	1990/91		1991/92		1992/93		Mean	
Genotype	Rainfed*	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated
ICPL 366	23·3	22·2	21·3	20·7	23·3	18·9	22·6	20·6
ICPL 87143	21·8	22·0	25·6	24·2	20·4	24·8	22·6	23·7
ICP 8860	17·4	17·8	23·4	24·0	17·4	17·3	19·4	19·7
NP (WR) 15	20·2	17·3	20·9	22·3	20·0	17·6	20·3	19·1
ICP 9174	17·5	20·1	25·8	25·2	20·3	18·8	21·2	21·4
ICPL 84072	21·6	21·2	20·7	23·3	19·2	27·8	20·5	24·1
Gwalior 3	18·9	15·5	28·8	23·5	16·6	13·1	21·4	17·4
Bahar	19·7	20·4	22·0	25·1	17·5	18·1	19·7	21·2
Mean	20·4	19·6	23·6	23·5	19·3	19·5	21·0	20·9
	1990/91		1991/92		1992/93		Mean	
	60 × 40 cm†	120 × 40 cm	60 × 40 cm	120 × 40 cm	60 × 40 cm	120 × 40 cm	60 × 40 cm	120 × 40 cm
ICPL 366	22·4	23·1	19·8	22·2	20·6	21·6	20·9	22·3
ICPL 87143	22·2	21·6	23·5	26·5	23·1	22·0	22·9	23·3
ICP 8860	16·7	18·4	22·5	24·9	16·0	18·7	18·4	20·7
NP (WR) 15	18·1	19·4	20·0	23·2	16·8	20·9	18·3	21·2
ICP 9174	18·8	18·9	24·2	26·8	19·4	19·7	20·8	21·8
ICPL 84072	30·7	22·2	21·5	22·5	20·5	26·5	20·9	23·7
Gwalior 3	16·8	17·6	25·2	27·0	14·4	13·3	18·8	20·0
Bahar	19·5	20·5	22·9	24·2	15·1	20·5	19·2	21·8
Mean	19·4	20·2	22·4	24·7	18·2	20·6	20·0	21·8

S.E. ± 0·38 (irrigation), 0·76 (genotype), 1·50 (season × genotype), 1·07 (irrigation × genotype), 0·30 (spacing).
CV (%) 17·0
*, Mean of 60 × 40 cm and 120 × 40 cm spacings.
†, Mean of rainfed and irrigated treatments.

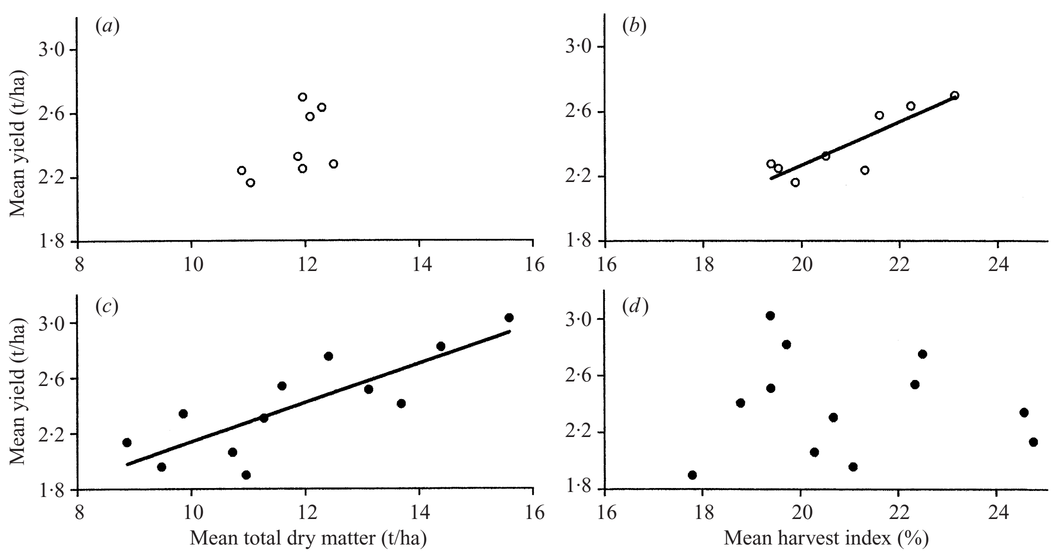

Fig. 3. Relationship of mean grain yield with (*a*) mean total dry matter and (*b*) harvest index across 8 genotypes, and mean grain yield with (*c*) mean total dry matter and (*d*) mean harvest index, across 12 environments at Gwalior, of the long-duration pigeonpea genotypes grown on Inceptisol at Gwalior, India during 1990–93 (○, genotype; ●, environment; line indicates the fitted regression).

that would inhibit pod set (Saxena *et al.* 1985). It should therefore only be possible to mitigate its effects mainly by developing drought-resistant genotypes. In this context it is important to know the comparative response to irrigation of other food legumes with pigeonpea. The comparative response of phenology and seed yield and its components to prolonged water deficits in soyabean, green gram, black gram, cowpea, lablab bean and pigeonpea was studied by Muchow (1985) during the dry season in semi-arid tropical Australia. He reported that under well-watered conditions, seed yields were similar in green gram, cowpea, soyabean and pigeonpea, with slightly higher yields obtained in black gram and lablab bean. However, under water deficit, the yield of pigeonpea declined by about 84% while that of other tropical grain legumes tested ranged between 61 to 89% relative to well-watered control. In general the longer the duration the greater was the reduction in grain yield under water deficit.

Seasons had significant interaction with genotypes for yield. Yield of all genotypes except that of Gwalior 3 and ICP 8860 declined somewhat linearly from the 1990/91 season to 1992/93 season; for Gwalior 3 and ICP 8860 highest yield was obtained in the 1991/92 season. The reasons for this are not clear. Pod fly damage, a major yield reducer in the region, was kept under control by appropriate insecticide use. In terms of weather, the 1991/92 season was characterized by an above average temperature during July and an above average rainfall during August.

All three advanced breeding lines, ICPL 366, ICPL 87143 and ICPL 84072, were superior yielding than the cultivars or germplasm lines. Breeding and selection of these long-duration pigeonpea for yield has been largely done under moisture stress free situations to minimize the effect of terminal drought stress and allow expression of yield potential. Since the long-duration pigeonpea is largely grown under rainfed conditions, it was suspected that this could lead to development of drought susceptible genotypes. In the present study, lack of interaction between genotype and irrigation treatments suggested that the landraces and advanced breeding lines were equally affected by terminal drought. Further, the rainfed yield was highly significantly correlated ($r = 0{\cdot}63^{**}$) with the irrigated yield and that irrigated yield could determine about 40% of the total yield variation in the rainfed conditions. This positive correlation between the rainfed yield and irrigated yield and a lack of significant genotype × irrigation clearly suggest that the yield improvement efforts for LDP under irrigated condition have not necessarily led to development of terminal drought susceptible genotypes, rather it has raised yields in rainfed conditions also.

Terminal drought reduced plant dry matter production by 15% but this could have been partly due to an increase in fallen leaves which were not recorded. Surprisingly, a lack of response of harvest index to irrigation was noted. Since harvest index is a function of water use after anthesis (Passioura 1997), it was expected to be low in the rainfed treatments. While total dry matter explained a large amount of variation in yield across the 12 environment combinations, it explained very little variation across genotypes. A lack of significant difference among genotypes for total dry matter was quite expected since they are of similar maturity. This suggests that any season effect in combination with agronomic practices that would lead to high dry matter production may lead to higher yield of LDP but may not cause appreciable differences among genotypes. In contrast, harvest index accounted for a large amount of variation in yield across genotypes but not across environments. Thus significant differences in yield among genotypes arose because of differences in harvest index. The advanced breeding lines were higher yielding because of higher harvest index. The improvement in harvest index has been the key factor in the improvement of yield in cereals such as rice and wheat (Evans 1980). This is perhaps one of the few reports to suggest that improvement in harvest index has been the basis for improvement in the yield of long-duration pigeonpea, although several studies have attributed low harvest index to be the prime reason for their low yield (Jain 1975). Thus there may be some scope for using harvest index as a selection criterion for enhancing yield of long-duration pigeonpea. While doing so, it was expected that selection for high harvest index would result in genotypes having relatively less vegetative dry matter. This means that there will be relatively less output of pigeonpea straw or stalks which is mostly used as a source of fuelwood or building material for fencing etc. especially in rural areas. Generally, farmers' preference is for increased grain yield thus increased income rather than the straw in the case of pigeonpea. Since in the present study, we did not notice any negative correlation between harvest index and total dry matter across genotypes, which is sometimes the reason for lack of gain in yield when harvest index is used as a selection criterion, this was not of much concern.

The results of this study have implications for optimizing yield of long-duration pigeonpea in different environments. Since across environments, yield was a function of total dry matter, agronomic practices (e.g. use of appropriate plant population, sowing time, land management) should be determined that would enhance dry matter production at minimum cost. This in combination with genotypes with high harvest index should result in high overall yield. Lack of a significant negative relationship between total dry matter and harvest index suggests that increase in one trait need not lead to reduction in another, rather an increase in both should be feasible which should result in higher yields.

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