Journal of Agricultural Science, Cambridge (2001), **136**, 179–189. *Printed in the United Kingdom*

Effect of timing of drought stress on growth and grain yield of extra-short-duration pigeonpea lines

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(*Revised MS received 3 August 2000*)

SUMMARY

Four extra-short-duration (ESD) lines in 1991 and eight ESD lines in 1992 were grown with adequate soil moisture throughout their growth or subjected to drought coinciding with the vegetative, flowering and pod-filling stages under rainout shelters. In both years, drought stress treatments significantly reduced dry matter accumulation and grain yield. The extent of reduction in grain yield varied with the line and stage of stress imposition. Drought stress at the flowering stage caused greater reduction in total dry matter and grain yield than the stress imposed during the pre-flowering and pod-filling stages. Drought stress coinciding with the flowering stage reduced grain yield by 40–55% in 1991 and 15–40% in 1992 in different lines. ESD genotypes could extract moisture from up to a metre depth during pre-flowering and flowering stage stress but less so during the pod-filling stage stress. Genotype ICPL 88039, followed by ICPL 89021, showed consistently lowest sensitivity to drought stress at flowering. Protracted drought stress commencing from the pre-flowering to flowering or from the flowering to pod-filling stages was more harmful than stress at the individual stages. The reduction in yield under drought stress could be attributed mainly to less total dry matter accumulation, but also increased abscission of plant parts. The results suggest variation in sensitivity of ESD lines in relation to timing of stress, which should facilitate targeted screening for different intermittent moisture stress environments.

INTRODUCTION

The recently developed extra-short-duration (ESD) pigeonpea [*Cajanus cajan* (L.) Millsp.] cultivars maturing in less than 120 days match the length of the rainy season in many traditional pigeonpea growing regions. The ESD trait enables them to escape the severe terminal drought to which short- and medium-duration cultivars may be exposed (Nam *et al.* 1993). However, ESD cultivars rely largely on current rainfall, and therefore have been reported to experience intermittent stress under 3-week or longer dry spells (Chauhan *et al.* 1993). To successfully replace longer duration cultivars in terminal drought stress-prone environments they should therefore also possess adequate levels of resistance to intermittent drought stress. In other crops, responses to intermittent drought stress have been shown to depend on the growth stage at which the stress occurs (Turk *et al.* 1980; Nageswara Rao *et al.* 1985; Gallegos & Shibata 1989). Considerable variation in tolerance to intermittent drought has been observed in short-duration pigeonpea lines and variation in sensitivity in relation to timing of drought stress has been established (Lopez *et al.* 1996). However, little information is available on responses of ESD lines to timing of intermittent stress, due to their relatively recent development (Laxman Singh *et al.* 1990). The objective of the present study therefore was to examine the effect of different drought stress timings on the growth and yield of a range of promising ESD developed mainly for yield.

MATERIALS AND METHODS

Soil and cultural practices

Two experiments were conducted in 1991 and 1992 on Alfisol (Udic Rhodustalf) fields at ICRISAT Asia Center, India (17° N, 78° E; 500 m above sea level) having maximum plant available water holding capacities of 60–100 mm to a metre depth. In 1991, an experiment (Expt 1) was conducted under two rainout shelters (ROS) that closed automatically to prevent rain on an experimental area of 50 m × 25 m. In 1992, an experiment (Expt 2) was conducted using a set of manually operated ROS consisting of 7·5 m wide, 15 m long and 2·0 m high (at mid-point) gabled metal

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frames covered by polythene sheets (Chauhan *et al.* 1997). Soil was surface tilled incorporating 100 kg/ha of diammonium phosphate, and prepared into ridges spaced at 0·6-m intervals. Prior to experimentation, soil analysis and plant growth tests had established that nutrient deficiencies would be unlikely in this soil (previously regularly fertilized) and that the native *Rhizobium* was adequate to ensure optimum nodulation and nitrogen fixation of pigeonpea. Agronomic operations were carried out as necessary for adequate protection against pests, disease and weeds. Seeds were treated with thiram (Bis(dimethylthiocarbamoyl) disulphide) and metalaxyl (*N*-(2,6-Dimethylphenyl)-*N*-(methoxyacetyl)-D,L-alanine methylester) (750 g/kg) at the rate of 3 g/kg of seed before sowing to control soil-borne fungal diseases. Sowing was done in shallow furrows on both sides of 60-cm ridges with 30-cm inter-row and 10-cm intra-row spacing. Two seeds/hill were sown and thinned at 20 to 25 days after sowing (DAS) to one seedling/hill to achieve a plant density of 33 plants/m^2. A pre-emergence herbicide mixture containing fluchlorolin (*N*-(2-chloroethyl)-2,6-dinitro-*N*-propyl-4-(trifluoromethyl) alanine) (450 g/kg) at 1·5 kg/ha with promotryn (*N*,*N*′-bis (1-methylethyl)-6-(methylthio)-1,3,5-triazine-2,4-diamine) (500 g/kg) at 1·5 kg/ha and paraquat (1,1′-dimethyl-4,4′-bipyridyldiylium ion) (2·5 g/kg) at 4·0 kg/ha was applied one day after sowing, with additional hand weedings as necessary. To control pod borer (*Helicoverpa armigera*) and spotted borer (*Maruca testulalis*), endosulfan (1,4,5,6,7,7-hexachloro-5-norbornene-2,3-dimethnol cyclic sulfite) (350 g/kg) at 2 kg/ha or monocrotophos (3-(dimethoxyphosphinoyloxy)-*N*-methylisocrotonamide) (360 g/kg) at 1·0 kg/ha during the flowering stage and quinalphos (*O*,*O*-diethyl-*O*-2-quinoxalinyl phosphorothioate) (250 g/kg) or methomyl (methyl *N*-[(methylcarbomoyl)oxy]thioacetimidate]) (240 g/kg) at 2 kg/ha during the pod-filling stage were applied. Metalaxyl (750 g/kg) at 1·0 to 2·0 kg/ha was also sprayed two times during the growing period to control *Phytophthora* blight.

Treatments and design

Expt 1: The following six drought stress treatments were assigned to the main plots of a split plot design in 1991:

1. Pre-flowering-stress (PRFLST) – irrigation withheld from 40 to 60 DAS.
2. Flowering stress (FLST) – irrigation withheld from 55 to 75 DAS.
3. Pod-filling stress (PFILLST) – irrigation withheld from 75 DAS to harvest.
4. Pre-flowering + flowering stress (PRFL + FLST) – irrigation withheld from 40–75 DAS.
5. Flowering + pod-filling stress (FL + PFILLST) – irrigation withheld from 55 to 75 DAS.
6. No-stress (NST) – irrigated throughout the growing season.

The main plot size was 3 × 10 m. Main plots were separated by 1·2-m wide border strips to minimize water seepage from the adjacent main plots. There were three replications. Sowing was done on 30 May 1991. Two determinate lines ICPL 84023, ICPL 89021, and two indeterminate lines ICPL 88039 and ICPL 89002 were assigned to subplots measuring 3 × 2·5 m. The plots were kept rainfed for the initial 15 days following which shelters were activated throughout the growing period in order to impose the desired soil moisture treatments. Water to each main plot was applied through a drip irrigation system at 3–5 day intervals to meet the evapo-transpiration demand. This was done by closing lateral irrigation lines to the main plot for the duration specified above for different treatments creating drought stress treatments.

Expt 2: In 1992, an experiment was laid out in split-plot design with drought stress as treatments in main plots and pigeonpea lines in subplots. The main plot treatments were:

1. Pre-flowering-stress (PRFLST) irrigation withheld from 35–55 days after sowing.
2. Flowering-stress (FLST) irrigation withheld from 55–80 DAS.
3. Pod-filling-stress (PFILLST) irrigation withheld from 80 DAS to harvest.
4. No-stress (NST) – irrigated throughout the growing season.

The main plot size measured 6 × 12 m. There were three replications. Sowing was done on 16 June 1992. Eight lines, which included four of those used in 1991, and ICPL 88007, ICPL 83015 (both determinate), ICPL 87111 and ICPL 88032 (both indeterminate) were used in this season. The crop was established with the onset of rain. A further irrigation was given to ensure good emergence and even crop establishment. Furrow irrigation was applied to meet the evapo-transpiration demand by opening the pipe gates spaced at 60-cm distances. Unlike in 1991, the NST treatment continued to receive rainfall throughout the cropping period as rain was not excluded from the NST treatment at any stage. The shelters were used only to cover the stress treatments. The other treatment plots also received rainfall throughout the cropping period except for the duration of treatment imposition when it was excluded by manually operated rainout shelters. Stopping irrigation and closing the shelters during rainfall imposed the stress treatments.

The extent of irrigation water applied was recorded through flow meters installed on the main irrigation lines. Soil moisture during crop growth in each main plot of both experiments was monitored in ICPL

88039 and ICPL 84023 plots at weekly intervals to a depth of 15–105 cm by a neutron probe (Model 2651 Troxler Electronic Laboratories Inc., USA). Soil moisture in the 0–15 cm layer was determined gravimetrically. The gravimetric moisture content and that derived from the calibration of count ratio of neutron moisture meter with gravimetric soil moisture was converted into volumetric moisture content (cm^3/cm^3). This was further converted into the amount of available water (cm) by multiplying it with the layer thickness. Mean values for the two genotypes were calculated as there were no differences apparent between the two genotypes on which measurements were made.

Time to 50 % flowering of a line was determined as number of days from sowing to the date when 50 % of the plants of the plot had at least one open flower. Days to maturity of a line were calculated as number of days from sowing to the time when more than 75 % of the pods had turned brown. These phenology criteria were equally measurable on determinate and indeterminate lines. Canopy light interception (LI) was measured at mid-day by using a line quantum sensor (Li-Cor Inc., USA). The line quantum sensor was placed across crop rows below the canopy to measure the radiation transmitted to the ground (I) while a quantum sensor was placed above the canopy to measure the total incoming radiation (I_0). The output of both the sensors was simultaneously recorded using a polycorder (Omni-data, International Inc., USA) and later transferred to a computer. The LI (%) was calculated using the following equation:

$$LI\ (\%) = [(I_0 - I)/I_0] \times 100$$

Destructive growth analysis was done on a sample of three contiguous plants per treatment which were cut at the base of stem at the end of each stress period. Plant samples were transferred to the laboratory in polythene bags and kept in the cool room at 5 °C until separation into different plant parts (leaves, stem, pods and flowers). This was completed on the same day for a sample. Leaf area was measured using an automatic leaf area meter (ΔT Devices, Cambridge, UK). Leaf area index (LAI) was calculated as LAI = leaf area/ground area. Dry matter was determined for leaves, stems and reproductive structures after oven drying for 48 h at 80 °C. The fallen plant parts (leaves, flowers and pods) from each treatment plot were collected in four 36 × 25 cm trays placed under the canopy between inter-row spaces at weekly intervals. The fallen leaves, flowers and pods in each sample were separated, and weighed after pooling with other samples and oven drying. Grain yield was determined by weighing mature sun-dried seeds (10 % moisture) from 4·5 m^2 harvested area and yield components from a three-plant subsample of pods. Total above ground vegetative dry matter was determined from the entire net plot sample of 4·5 m^2. The total dry matter (TDM) included oven dry above ground vegetative plant parts, sun-dried seeds and pod-walls but not the fallen plant parts.

The data were subjected to analysis of variance using a standard split-plot design analysis as described by Gomez & Gomez (1984) by means of the GENSTAT package on a Digital®VAX mainframe computer system. Relationships of yield with plant growth parameters were determined using regression analysis.

RESULTS

Soil moisture extraction during stress

The amount of water used by the crop including irrigation, rainfall and that extracted from the soil profile during the stress period is given in Fig. 1. The contribution of rain to the moisture used was negligible in 1991 as the entire experimental site was covered by the ROS. In contrast, in 1992 when ROS excluded rain only during the stress period, the rainfall constituted the major portion of total water used. There was considerable depletion of moisture from the entire 105-cm soil profile during the PRFLST and FLST, and PRFLST + PFILLST, and FLST + PFILLST stresses. In contrast, during PFILLST stress the extraction was largely from the surface down to the 60 cm layer, even though considerable moisture was available in the > 60 cm layers (Fig. 2). This could be due to a lack of active roots in the deeper layers. There was relatively low moisture in the 0–15 cm layers during PRFLST, which may be due to quick drying of the surface by sun rays and wind as canopy cover was not complete by then, as well as the

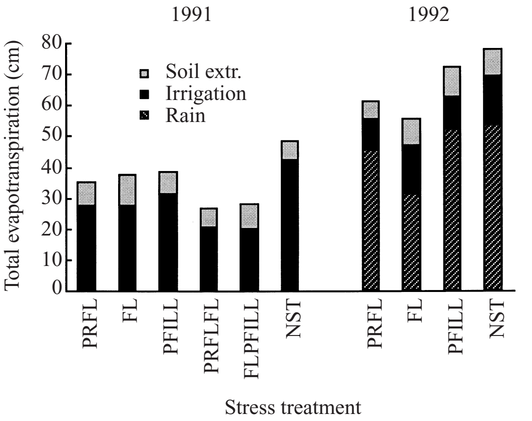

Fig. 1. Mean total water used by extra-short-duration pigeonpea lines under the pre-flowering (PRFL), flowering (FL), pod-filling (PFILL), pre-flowering + flowering (PRFLFL), flowering + pod-filling (FLPFILL), and control (NST) treatments during the 1991 and 1992 seasons.

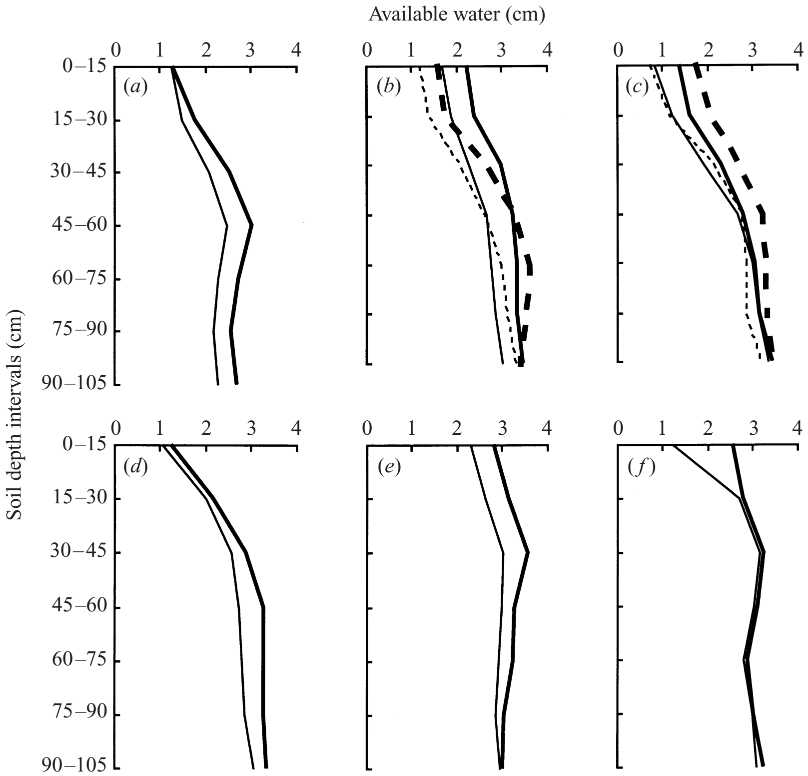

Fig. 2. Water extraction pattern of extra-short-duration pigeonpea during the pre-flowering (*a*, *d*), flowering (*b*, *e*) and pod-filling stages (*c*, *f*) in the 1991 (*a*, *b*, *c*), and 1992 (*d*, *e*, *f*) seasons. The thicker lines represent moisture status before the imposition of stress and thin lines at the end of stress. Continuous lines represent single stage stress and whereas dashed lines represent extended stress (*b*) beginning at the pre-flowering stage and ending with the flowering stage stress, and (*c*) beginning at the flowering stage and ending with the pod-filling stage stress. The difference between respective thick and thin lines is the amount of moisture used during the stress period at different depths.

presence of active roots. Unlike 1991, the plots in 1992 continued to receive rainfall throughout the cropping period except for the duration of the respective treatment imposition period when they were covered by manually operated rainout shelters. The total water applied in 1992 therefore was much greater, which was reflected in generally higher soil moisture at different stages (Fig. 2). The soil water status at the beginning of stress imposition did not vary among the designated treatments within each season (Fig. 2). However, differences between the control and the stress treatments occurred at the end of stress periods. In 1991, there was greater depletion of soil moisture in the deeper layers in the NST than the FLST or PFILLST or protracted drought treatments, whereas there was greater extraction in the surface (0–30 cm) layers in the drought stress treatments. In 1992, in the pre-flowering, flowering and pod-filling stresses water was extracted down to 75 cm. The greater extraction of moisture from the deeper layers in NST, however, was not obvious probably due to greater replenishment from rainfall, as rain was not excluded from the control plots.

Phenology

Time to 50% flowering of all the lines was within 47–60 days (Table 1). PRFLST did not significantly affect it in either season. Drought stress during the flowering and pod-filling stages hastened crop maturity by 1–3 days in both years (Table 1). Drought stress during the pre-flowering stage delayed crop maturity by 3 days in 1992 as an additional reproductive flush was produced upon re-watering.

Canopy development and light interception

The PRFLST treatment significantly reduced LAI of all lines at the end of this stress by 15–20% in 1991 and by 35–60% in 1992 (Fig. 3*a*). The differences among lines were not significant in 1991, but highly

Table 1. *Effect of drought stress timings on phenology of extra-short-duration pigeonpea during the 1991 and 1992 rainy seasons*

Treatment	50% flowering		Physiological maturity	
	1991	1992	1991	1992
Timing of drought stress				
Pre-flowering	57	51	93	96
Flowering	57	52	91	93
Pod-fill	57	51	92	93
Pre-flowering and flowering	57	—*	92	—
Flowering and pod-fill	57	—	91	—
No-stress	57	51	94	94
Line†				
ICPL 83015	—	52	—	95
ICPL 84023	56	50	89	93
ICPL 86007	—	50	—	92
ICPL 89021	52	47	85	85
ICPL 87111	—	53	—	97
ICPL 88032	—	54	—	97
ICPL 88039	60	51	97	95
ICPL 89002	61	53	98	96
S.E.				
(±) Stress (S)	0·3	0·1	0·3	0·4
Line (L)	0·2	0·2	0·2	0·5
S × L	0·5	0·4	0·5	0·9

* Not tested.

† The first four lines are determinate and last four lines are indeterminate.

significant in 1992. Among the lines tested LAI of lines ICPL 83015, ICPL 84023, ICPL 87111 and ICPL 88032 were significantly reduced by PRFLST. Lines ICPL 88039, ICPL 86007, ICPL 83015 and ICPL 89002 could retain higher LAI than the other lines under this stress. FLST significantly reduced LAI of all lines at the end of this stress in 1991 but not in 1992 (Fig. 3*b*). There was a 30–55% reduction of LAI in stress treatments compared with NST in 1991 at the flowering stage. Line ICPL 84023 showed a smaller reduction in LAI than the other lines under this stress. At the end of PFILLST, lines such as ICPL 88039 in 1991 and ICPL 84023 and ICPL 86007 in 1992 maintained relatively higher LAI in this treatment compared to NST (Fig. 3*c*).

Fractional light interception (F) was highly sensitive to drought as it declined significantly just after the imposition of stress and increased only marginally after drought was relieved (Fig. 4). At the end of PRFLST, F reduced to about 50% in 1991 (Fig. 4*a*) and to about 55% in 1992 (Fig. 4*b*). The FLST had a greater effect than the other stress timings on reducing F in 1991 (Fig. 4*a*) whereas the effect was only apparent very late in the season in 1992 (Fig. 4*b*). Fractional light interception was reduced in the stress treatment to about 50% compared to NST at the end of this stress. The differences in F were significant only when compared to NST, but the differences were not significant among the other stress treatments in 1992. The moisture stress × line interaction was also not significant in both years (data not shown).

Dry matter production and abscission

At the end of respective stress treatments, total dry matter (TDM) accumulation among lines was significantly reduced by drought stress treatments. The extent of reduction, however, varied in relation to timing of stress imposition (Table 2). The PRFLST treatment caused 30–50% reduction in TDM among different lines and the effect of stress was more severe in 1992 than in 1991. The FLST treatment caused up to 37% reduction in TDM by the end of stress with maximum reduction being in ICPL 89002 in 1991 and ICPL 83015 in 1992. ICPL 89002 showed no reduction in TDM in 1992, which could be sampling error introduced by a small sample size. PFILLST reduced TDM by 45–55% compared with the NST treatment in 1991 whereas the reduction was much smaller in 1992. At the end of PFILLST, TDM declined largely due to senescence.

The differences in TDM at harvest for timings of stress, line and stress × line interactions were significant in both years (Table 3). At harvest, TDM in the NST treatment was 6–7 t/ha, which was significantly reduced by the stress treatments. The FLST treatment

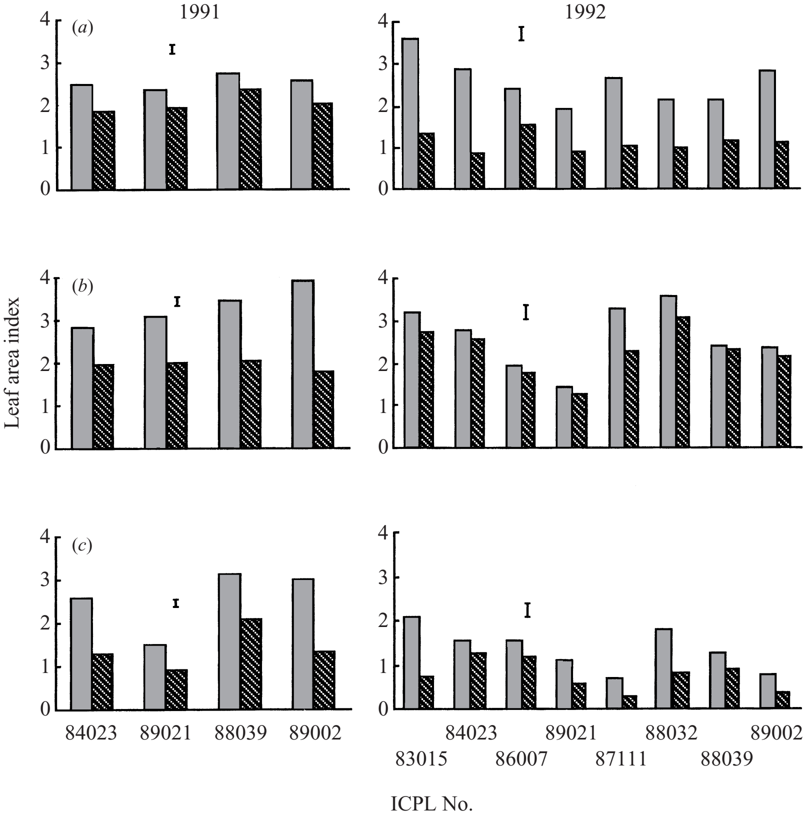

Fig. 3. Leaf area index of different extra-short-duration pigeonpea lines (ICPL No.) after water stress imposed at the (*a*) pre-flowering (PRFLST), (*b*) flowering (FLST), and (*c*) pod-filling (PFILLST) stages in the 1991 and 1992 seasons. Shaded bars represent the no stress control and hatched bars represent the stress treatment. Vertical bars (I) are S.E. for comparisons.

had a larger negative effect than PRFLST or PFILLST. The PRFL+FLST and FL+PFILLST had an even greater negative effect than FLST, reducing TDM by more than 50%. Generally, lines ICPL 89021 and ICPL 89002 appeared more susceptible to drought at the flowering stage in both years.

There were highly significant differences in amount of leaf and flower drop in different stress treatments (Fig. 5). Pod drop was relatively small even in the PFILLST. Flower drop was more in the NST up to the end of FLST. There was greater abscission of leaves in the stress treatments than in the NST treatment.

Grain yield

The drought stress treatments resulted in significant reduction in grain yield in both years (Table 4). However, the degree of yield reduction varied in relation to timing of drought stress, its duration, and the ESD pigeonpea line. With adequate moisture supply, all lines produced yields of about 2 t/ha or more. Lines such as ICPL 83015, ICPL 84023 and ICPL 88032 gave high yield in NST. The PRFLST treatment reduced grain yield by 15–30% in 1991 and 10–40% in 1992 (Table 4). ICPL 84023 was the highest yielding line under PRFLST in 1991. The FLST treatment was most damaging to yield, causing 40–55% reduction in 1991 and 15–40% reduction in 1992. ICPL 88039 followed by ICPL 89021 was consistently the highest yielding line in the FLST. The PFILLST treatment caused least yield reduction, only 15–20% in the two seasons. ICPL 89021 in 1991, and ICPL 83015 in 1992, gave the highest yield and ICPL 89002 lowest yield in PFILLST. In the extended stress (PRFL+FLST and FL+PFILLST) treatments in 1991, grain yield was 39% of the NST treatment. The stress treatment × line interactions was significant in both 1991 and 1992. There were differences in yield under well-watered conditions. However, there was no relationship between yield of lines under drought and yield under well-watered conditions.

The correlation of grain yield with TDM at harvest was 0·939 ($n = 24$) in 1991, and 0·789 ($n = 32$) in 1992.

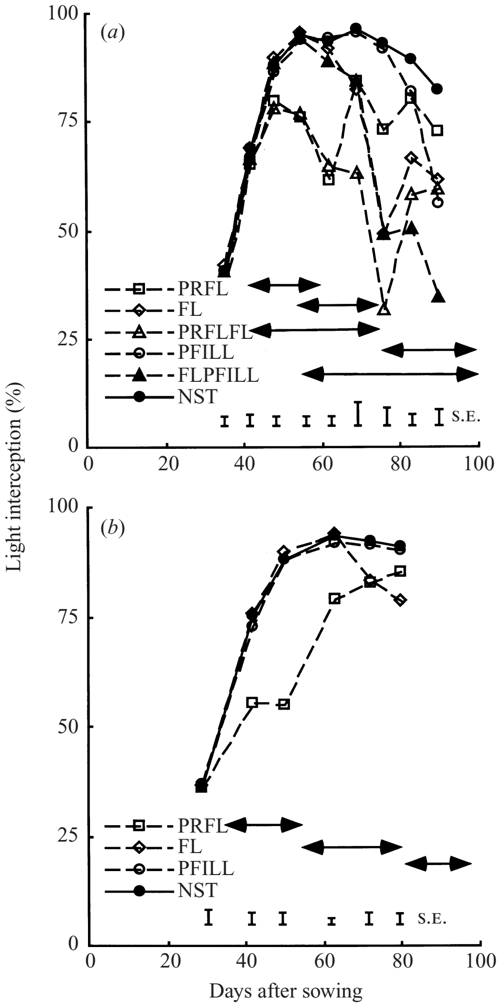

Fig. 4. Light interception pattern of extra-short-duration pigeonpea lines in the pre-flowering (PRFL), flowering (FLST), pod-filling (PFILL), pre-flowering+flowering (PRFLFL), flowering+pod-filling (FLPFILL), and control (NST) treatments in the (*a*) 1991 and (*b*) 1992 seasons. Vertical bars (I) are S.E. for comparisons and horizontal arrows against the symbol legends indicate the duration of the stress period.

In contrast, the relationship of yield with LAI both at the end of PRFLST and FLST was not significant in both years. The relationship of LAI at the end of PFILLST and grain yield was significant ($r = 0{\cdot}836$, $n = 6$) only in the NST in 1992.

DISCUSSION

The grain yields of ESD pigeonpea in the no-stress treatment ranged from 2·0 to 2·5 t/ha in both years, which were similar to the highest yield levels achieved in normal sowings on Alfisol irrespective of maturity duration (Chauhan *et al.* 1993; Nam *et al.* 1993). Such yields are, however, generally not realized under drought. A large variation in the grain yield recorded in different treatments of this study reflected the sensitivity of ESD pigeonpea to different drought stress timings. A lack of significant correlation between yield under stress at different stages and the control treatments suggests a requirement for identifying resistant lines to each type of drought, although it is difficult to contemplate in a breeding programme. In the present study, it was facilitated by rain exclusion using rainout shelters during the typical growing season. Such screening is likely to be more realistic than screening performed in the off-season, in order to avoid rain spoiling the treatments, because photoperiod and temperature regimes are likely to be different then.

The existence of a significant differential response among lines to drought stress treatment timings indicated the possibility of alleviating the adverse effects by appropriate selection of lines for different stress environments. In earlier studies, short-duration indeterminate lines were found to be more drought-tolerant than the determinate lines (Lopez *et al.* 1996). In the present study no clear-cut advantage of indeterminate growth habit over determinate growth habit was observed. Under drought stress, the advantage of indeterminate growth habit, unlike in the later maturity types, seems to decrease among ESD lines with fewer branches (growth points) present to continue growth. Indeed, this could be the reason for the relative abundance of determinate types in the ESD group than the later maturing groups (Remanandan 1990).

Drought at the flowering stage caused most yield reduction, from 20 to 63% among different lines. Drought stress at this stage has been found to be more damaging than that at other growth stages in other legumes as well; such as soybean (Kpoghomou *et al.* 1990), cowpea (Turk *et al.* 1980), groundnut (Boote *et al.* 1982; Nageswara Rao *et al.* 1985) and short-duration pigeonpea (Lopez *et al.* 1996). Relatively greater reduction in yield of ESD lines was observed in 1991 than in 1992, although the duration of the stress was shorter. Notwithstanding the differences in the magnitude of stress, the differences among lines were significant in both years with ICPL 83015, ICPL 84023 and ICPL 88032 suffering more by this stress while ICPL 88039 was relatively less affected in both years.

The pre-flowering stage stress reduced grain yield by 11–45% among different lines compared to the control. Generally, ESD lines such as ICPL 84023 and ICPL 88039 in 1991, and ICPL 83015 and ICPL 86007 in 1992 were less affected by the PRFLST stress. Grain yield of ICPL 89021 and ICPL 88032 showed relatively more sensitivity to PRFLST stress.

Table 2. *Effect of timing of drought stress* on total dry matter* (*t/ha*) *at the end of different stress treatments of extra-short-duration pigeonpea lines during the 1991 and 1992 rainy seasons*

	PRFL		FL		PFILL	
Line	Stress	NST	Stress	NST	Stress	NST
Rainy season 1991						
ICPL 84023	1·65	1·88	3·16	3·63	5·01	7·20
ICPL 89021	1·87	1·98	3·56	3·95	6·55	5·98
ICPL 88039	1·88	2·24	3·15	4·63	4·91	7·99
ICPL 89002	1·67	1·91	2·86	4·55	5·34	7·04
S.E. (±)	0·207		0·258		0·521	
Rainy season 1992						
ICPL 83015	1·49	2·97	3·81	6·03	5·84	6·81
ICPL 84023	1·13	2·71	4·93	5·65	6·34	6·95
ICPL 86007	1·58	2·27	3·46	4·73	5·01	6·31
ICPL 89021	1·36	2·40	3·97	5·09	5·15	5·88
ICPL 87111	1·30	2·48	3·79	5·86	5·61	5·83
ICPL 88032	1·06	1·91	4·85	6·15	5·16	7·27
ICPL 88039	1·41	2·30	4·51	4·66	5·22	6·33
ICPL 89002	1·65	2·60	4·58	4·45	5·23	5·49
S.E. (±)	0·272		0·581		0·884	

* Timing of stress: PRFL, pre-flowering; FL, flowering; PFILL, pod-filling stage stresses; NST, no stress control.

Water stress during the pre-flowering stage did not advance the time to flowering of ESD lines. In cowpea, a high degree of phenological plasticity has been observed which enables it to shorten or lengthen its reproductive period depending upon water availability (Muchow 1985). A lack of phenological plasticity in ESD lines may make them more sensitive to intermittent drought than the short season legumes such as cowpea.

For improving drought resistance of ESD pigeonpea, exploiting differences in rooting depth and extraction of soil water at deeper layers seem necessary. ESD lines could extract water from as deep as 105 cm under PRFLST or FLST stresses, suggesting that they have the ability to extract moisture from deeper layers of the profile when these stresses are operating. Differences in root length and depth among all the lines were not compared in the present study.

Drought coinciding with the pod-filling stage caused up to 46% reduction in yield in the two seasons. Plants facing drought at this stage were not able to extract moisture from deeper layers than 60 cm probably due to lack of active roots. The severity of this stress can be partly reduced by remobilization of stored assimilates to pods as reported in soybean (Westgate *et al.* 1989) or through escape. For example, even the slightly earlier maturity of ICPL 89021 gave it a considerable advantage under PFILST. The severe reduction in yield by PRFL+FLST or FL+PFILLST was obviously because of the extended duration of the stress. ICPL 88039 and ICPL 89021 appeared better able to withstand the FL+PFILLST stress.

The genotypic differences in yield in response to drought at different stages were attributable to differences in TDM at maturity. Drought stresses can affect TDM production primarily through reduced accumulation and increased abscission of leaves thus reducing photosynthetic area, but also through reduced radiation use efficiency. In the present study, there was no relationship between leaf area index measured at the end of stress periods and TDM at maturity in any of the treatments. Nam *et al.* (1998) also found no relationship between the leaf area duration under stress and TDM at maturity. They observed that radiation use efficiency better explained the variation in TDM under stress and no stress situations for ESD lines. It appears that under NST a lack of association between LAI and TDM could be due to LAI being above optimum. Under stress, however, remaining leaf area functioning efficiently could compensate decline in leaf area, though the overall efficiency may still be less than in NST. There was no relationship of grain yield with leaf area accumulation in any of the treatments, but there was a significantly positive relationship between the TDM at maturity and yield.

The results of the study demonstrate that as in most other legumes, drought stress at flowering was most harmful for yield formation. There are, however, genetic differences in resistance to this stress, with ICPL 88039 being the most promising among the lines tested. The other stresses coinciding with the pre-flowering and pod-filling stages would also be important, especially if they extend or overlap other growth stages. Again, differences observed even

Table 3. *Effect of timing of drought stress* on total dry matter at harvest* (*t/ha*) *of extra-short-duration pigeonpea lines during the 1991 and 1992 rainy seasons*

Line	PRFL stress	FL stress	PFILL stress	PRFL+FL stress	FL+PFILL stress	NST
Rainy season 1991						
ICPL 84023	5·49	4·59	5·00	3·47	3·27	7·19
ICPL 89021	5·13	3·87	5·73	3·42	3·27	6·60
ICPL 88039	5·31	4·60	4·86	3·45	3·24	6·30
ICPL 89002	4·49	4·41	4·04	3·48	2·91	6·13
Mean	5·10	4·37	4·91	3·46	3·17	6·55
S.E. (±)						
Stress (S)			0·269			
Line (L)			0·081			
S × L			0·320 (0·200)			
Rainy season 1992						
ICPL 83015	5·82	4·79	6·21	—†	—	7·13
ICPL 84023	5·35	5·41	5·81	—	—	7·13
ICPL 86007	5·02	5·06	5·37	—	—	6·53
ICPL 89021	4·14	4·09	4·96	—	—	5·47
ICPL 87111	5·19	4·93	5·29	—	—	5·93
ICPL 88032	5·26	5·18	5·81	—	—	6·85
ICPL 88039	4·16	5·31	5·60	—	—	5·70
ICPL 89002	4·33	3·38	4·60	—	—	6·46
Mean	4·91	4·77	5·48	—	—	6·46
S.E. (±)						
Stress (S)			0·180			
Line (L)			0·136			
S × L			0·311 (0·272)‡			

* Timing of stress: PRFL, pre-flowering; FL, flowering; PFILL, pod-filling; PRFL+FL, pre-flowering+flowering; FL+PFILL, flowering+pod-filling; NST, no stress control.

† Not tested due to limited Rain Out Shelter availability.

‡ S.E. values in parentheses are used for comparing means at same levels of stress.

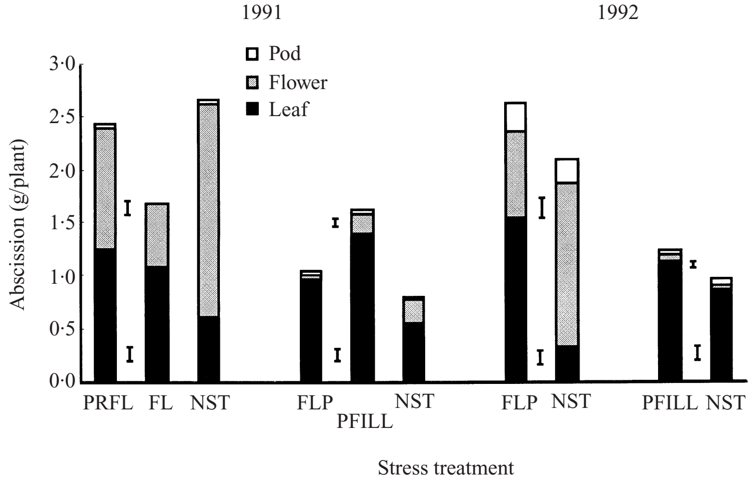

Fig. 5. Mean relative contribution of leaf, flower and pod drop to abscised dry matter (g/plant) of extra-short-duration pigeonpea lines in the pre-flowering+flowering (PRFL), flowering stress (FL) and control (NST) treatments recorded at the end of flowering stage stress; flowering+pod-filling stress (FLP), pod-filling stress (PFILL) and control (NST) treatments recorded at the end of pod-filling stage stress in the 1991 and 1992 seasons. Vertical bars (I) are S.E. for comparisons of leaves (lower) and flowers or pods (upper).

Table 4. *Effect of timing of drought stress* on grain yield (t/ha) of extra-short-duration pigeonpea lines during the 1991 and 1992 rainy seasons*

Line	PRFL	FL	PFILL	PRFL+FL	FL+PFILL	NST
Season 1991						
ICPL 84023	2·12	1·12	2·04	0·77	1·02	2·62
ICPL 89021	1·77	1·33	2·53	0·96	1·23	2·58
ICPL 88039	2·11	1·41	1·91	0·95	1·19	2·44
ICPL 89002	1·85	1·25	1·22	1·08	0·78	2·28
Mean	1·96	1·28	1·92	0·94	1·05	2·48
S.E. (±)						
Stress (S)				0·134		
Line (L)				0·034		
S × L				0·153		
Season 1992						
ICPL 83015	2·12	1·50	2·35	—†	—	2·40
ICPL 84023	1·68	1·64	2·20	—	—	2·46
ICPL 86007	1·89	1·60	2·02	—	—	2·13
ICPL 89021	1·60	1·72	2·05	—	—	2·02
ICPL 87111	1·67	1·48	1·88	—	—	1·97
ICPL 88032	1·38	1·35	2·06	—	—	2·50
ICPL 88039	1·69	1·76	2·09	—	—	2·19
ICPL 89002	1·61	1·32	1·76	—	—	2·07
Mean	1·70	1·55	2·05	—	—	2·22
S.E. (±)						
Stress (S)				0·083		
Line (L)				0·062		
S × L				0·142 (0·123)‡		

* Timing of stress: PRFL, pre-flowering; FL, flowering; PFILL, pod-filling; PRFL + FL, pre-flowering + flowering; FL + PFILL, flowering + pod-filling; NST, no stress control.

† Not tested due to limited Rain Out Shelter availability.

‡ S.E. values in parentheses are used for comparing means at same levels of stress.

among the limited set of lines that were tested suggested that the harmful effects of these could be alleviated through selection of an appropriate line for different stresses.

Although the intermittent stresses are quite difficult to predict, examining the long-term probability of rainfall (Virmani *et al.* 1982) and moisture holding capacity of the soil could allow assessment of the likelihood of drought coinciding with a particular growth stage. For example, the peninsular Indian environment has a probability of drought coinciding with the flowering stage in 4 out of a 10-year period whereas subtropical environments in India could encounter pre-flowering stress in 5 out of a 10-year period due to sparse rainfall in the early monsoon period. In the rain-shadow areas of Maharashtra State of India, pod-filling stress would be a more common (4 in 10 years) occurrence, whereas no stress would be generally experienced in Central India. It would be interesting to examine if lines selected for resistance to stress at a particular stage can result in better performance in respective drought environments. Line ICPL 88039 has since been extensively tested in farm conditions in northern India and has given about 10–19% more yield than the commonly grown cultivars in that environment (Dahiya *et al.* submitted). The yield advantage could be due to its greater resistance to drought among other factors such as its more synchronous flowering and its ability to escape/resist insect attack.

The senior author wishes to thank ICRISAT for a research fellowship and facilities to conduct research.

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