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ADAPTATION OF EXTRA SHORT DURATION PIGEONPEA TO RAINFED SEMI-ARID ENVIRONMENTS

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SUMMARY

The adaptation of extra short duration (ESD) pigeonpea (*Cajanus cajan*) genotypes to rainfed environments was studied on Alfisols and Vertisols at the ICRISAT Center between 1987 and 1989. Despite a slightly shorter crop duration, the grain yield of ESD genotypes was twice as large on Alfisols as on Vertisols. On both soil types, the rate of growth and grain yield were better in crops sown on time than in those where sowing was delayed. The population levels necessary to maximize yield varied among genotypes on Alfisols, where the grain yield of several ESD genotypes compared favourably with that of ICPL 87, a standard short duration genotype. However, none of the ESD genotypes yielded more than ICPL 87 on the Vertisols.

Adaptación del Cajanus cajan *de duración extra corta*

RESUMEN

Se estudió la adaptación de genotipos de *Cajanus cajan* de duración extra corta (DEC) a ambientes con precipitaciones naturales en Alfisols y Vertisols, en el ICRISAT Center, entre 1987 y 1989. A pesar de una duración de cultivo ligeramente inferior, el rendimiento de grano de los genotipos de DEC fue el doble en Alfisols que en Vertisols. En ambos tipos de suelo el índice de crecimiento y los rendimientos de grano fueron mejores para las cosechas sembradas a tiempo, que en las sembradas con retraso. Los niveles de población necesarios para maximizar el rendimiento variaron con los genotipos en los Alfisols, donde el rendimiento de grano promedio de diversos genotipos DEC se comparó favorablemente con el del ICPL 87, un genotipo de corta duración estándar. No obstante, ninguno de estos genotipos DEC produjo mayor rendimiento que el ICPL 87 en los Vertisols.

INTRODUCTION

Although pigeonpea has been described in the literature as a drought tolerant crop, it is adversely affected by droughts that occur towards the end of the growing season (ICRISAT, 1984; Muchow, 1985). The crop duration of traditional genotypes is often longer than the effective length of the cropping season so that yields are less than they might otherwise be (Singh and Subba Reddy, 1988). Such yield losses might be reduced by growing genotypes with a duration better matched to the periods of water availability (Lawn and Troedson, 1990), although this option has not so far been adequately explored.

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Table 1. *Chemical properties of the soils at the experimental sites*

	pH	Electrical conductivity (ds m^{-1})	Organic carbon (%)	Available P (mg kg^{-1} soil)	Available N (mg kg^{-1} soil)	Total N (mg kg^{-1} soil)
			Alfisols			
1987	7.5	0.08	nd	7.9	6.9	nd
1988	6.8	0.22	0.29	21.1	35.3	467
1989	6.2	0.16	0.43	34.5	62.2	656
			Vertisols			
1988	8.2	0.28	0.39	7.9	18.4	524
1989	8.3	0.18	0.45	24.7	45.7	562

Nd, not determined.

The need to use pigeonpea in more intensive cropping systems has led to the development of shorter duration genotypes (Laxman Singh *et al.*, 1990). Recently, several extra short duration (ESD) genotypes have been bred which mature in 90–110 days (Laxman Singh *et al.*, 1990). These genotypes might be useful for rainfed environments where the effective length of the cropping season is short. They might also be useful in multiple-cropping systems on soils with a high water holding capacity, such as Vertisols, to avoid the need for rainy season fallows.

Previous studies with short duration (SD) pigeonpea have shown that seed yield and total dry matter decline significantly when sowing is delayed beyond the longest day (Chauhan *et al.*, 1987), although some of the adverse effects of delayed sowing can be offset by increasing the plant population (Spence and Williams, 1972). Extra short duration genotypes take 20–30 days less to mature than short duration genotypes and may differ in their response to sowing date and plant population. The objectives of this study were therefore to evaluate the response of different ESD genotypes to sowing date and plant population and to compare their performance with a standard short duration genotype in order to determine their suitability for cultivation on Alfisols and Vertisols under rainfed conditions.

MATERIALS AND METHODS

Rainfed field experiments were conducted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India (18°N, 78°E, 540 m elevation) in the rainy seasons of 1987, 1988 and 1989. In 1987, the experiment was conducted on an Alfisol (Udic Rhodustalf) and in 1988 and 1989 on both Alfisols and Vertisols (Typic Pellustert). The available water holding capacity of the Alfisols is 60–100 mm and that of the Vertisols is about 200 mm. The chemical properties of soils at the experimental sites are shown in Table 1. Rainfall, evaporation and temperatures were recorded during the growing seasons and soil moisture storage and run-off were estimated using a water balance model (Keig and McAlpine, 1974).

The experimental design was a split-split-plot with three replications. Two sowing dates were assigned to the main plots, six genotypes to the sub-plots and three plant populations to the sub-sub-plots. The sub-sub-plot size was 3 × 4 m. The sowing dates were: 25 June and 7 August in 1987; 20 June and 27 July on the Alfisol and 16 June and 7 August on the Vertisol in 1988; and 30 June and 3 August on the Alfisol and 19 June and 2 August on the Vertisol in 1989. In each case, the first date given is the normal sowing date and the second date is the delayed sowing date. Four determinate genotypes, ICPL 83015, ICPL 84023, ICPL 85015 and ICPL 4, and two indeterminate genotypes, ICPL 85037 and ICPL 86020, were used in 1987. ICPL 86020 was replaced by a short duration genotype ICPL 87, used as a control, on both soil types in 1988 and 1989. ICPL 85015 was replaced by ICPH 73, an ESD hybrid, in 1989. The three plant populations used in each year were 16 plants m^{-2} (30 × 20 cm spacing), 33 plants m^{-2} (30 × 10 cm spacing) and 66 plants m^{-2} (30 × 5 cm spacing).

All sowing was done by hand in furrows opened on both sides of 60 cm ridges, to give an inter-row spacing of 30 cm. Intra-row spacings were maintained at 5, 10 or 20 cm by placing at least two seeds at precisely the required distance apart. Seedlings were thinned to one per hill at about 25–30 days after sowing (DAS).

All the experimental plots received a basal application of diammonium phosphate fertilizer at the recommended rate of 100 kg ha^{-1}. Plants were well nodulated with native *Rhizobium* which is abundant in these soils. Weeds were controlled by an application of a mixture of fluchloralin at 0.75 kg active ingredient (a.i.) ha^{-1} and prometryn at 1.25 kg a.i. ha^{-1} before crop emergence. In addition, plots were weeded at about 45 DAS. Insecticide was used to minimize damage by pod borer (*Helicoverpa armigera*) during the reproductive stage of the crop.

Actual plant population, light interception, and time taken to reach 50% flowering and 80% maturity were recorded in the crop. Canopy interception of photosynthetically active radiation (PAR) was estimated in 1989 as the ratio of PAR measured simultaneously by a line quantum sensor (1.0 m long) placed beneath the canopy and a point quantum sensor (LI-COR, Nebraska, USA) placed above the canopy between 1100 and 1400 local time. Both sensors had the same output when placed outside the canopy.

Plant samples were taken at 60 DAS to compare the differences in leaf area index (LAI) and dry matter production between treatments. Three plants were sampled from each sub-plot by cutting at the stem base. The leaves were separated from the harvested plants and the leaf area determined using an automatic leaf area meter (Delta-T Devices, Cambridge, England). The dry matter content of leaves and stems was measured separately after drying at 80°C to a constant mass.

Total above-ground recoverable dry matter (TADM) at maturity was estimated from a single row in each plot. The grain yield was estimated from a net

Table 2. *Rainfall (mm) received during the crop growing periods in 1987, 1988 and 1989 and the corresponding long-term (1974–1989) mean*

	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1987	143	144	98	62	149	240	1
1988	122	256	273	247	2	0	7
1989	99	416	109	286	27	0	6
Long-term mean	129	199	180	173	70	30	5

plot area of 9 m^2, which included the row sampled for TADM estimation. The seeds weighed for yield estimation had a moisture content of about 10%.

RESULTS

Weather and soil moisture

The total rainfall received during the June–December period in all the three growing seasons was more than the long-term (1974–89) mean (Table 2). In 1987 there was a dry spell in September, followed by considerable rainfall in November. In 1988 rainfall was well distributed throughout the rainy months (June to September), whereas in 1989 excess rainfall was received during July and September. This variation resulted in differences in soil moisture availability at different phenological stages during the three growing seasons (Fig. 1). In 1987, the soil moisture content was lower at the delayed sowing date, but higher during the reproductive phase, than at comparable stages in 1988 and 1989, when the soil moisture content at the time of the delayed sowings was much higher than at the normal sowing time. There was little run-off until at least four weeks after the normal sowing date in both soils. However, there was considerable run-off at the time of the delayed sowings, especially in 1988 and 1989 on the Alfisols and in 1989 on the Vertisol. There was more run-off at the time of delayed sowing on the Alfisols in 1989 than in 1988.

There were only small differences between sowings in thermal time and incident radiation for the first 60 days of growth (Table 3). Over the same period, evaporative demand was only 15% more for the normal than for the delayed sowings.

Crop growth and grain yield

The ESD genotypes flowered and matured 22–42 days earlier than the SD genotype, ICPL 87, following normal sowing (Table 4). This difference was reduced by 2–12 days following delayed sowing. On Alfisols, ESD genotypes took fewer days to flower and mature than on Vertisols.

Grain yield, TADM at 60 DAS and at maturity, and the LAI at 60 DAS differed between seasons (Table 5). The maximum grain yields were obtained in the 1988 season and they were twice as high on Alfisols as on Vertisols from comparable sowings. For both soil types, grain yield, TADM at 60 DAS and at maturity, and

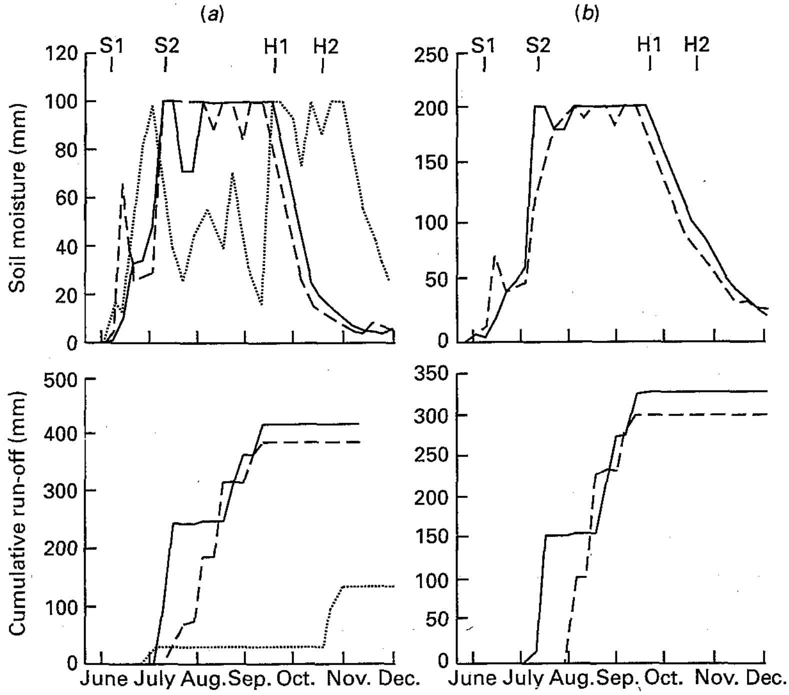

Fig. 1. Estimated soil moisture and cumulative run-off on (a) Alfisols and (b) Vertisols during the crop growing periods of 1987 (····), 1988 (– – –) and 1989 (———). Approximate times of sowing and harvest are also indicated: S1, normal sowing; S2, late sowing; H1, harvest of normal sowing; and H2, harvest of late sowing.

Table 3. *Thermal time (degree days above 10° C), pan evaporation (mm) and solar radiation (MJ m^{-2}) for the first 60 d after sowing, 1987–1989*

	Normal sowing			Delayed sowing		
	1987	1988	1989	1987	1988	1989
Thermal time	1005	978	936	993	939	930
Cumulative evaporation	338	287	279	304	222	254
Cumulative radiation	996	876	954	972	858	972

LAI were significantly greater following the normal sowing than following delayed sowings.

Light interception, measured throughout the crop growth period on the Alfisol in 1989, was greater at all stages in crops sown on time than in those where sowing was delayed (Fig. 2). The leaf area index at 60 DAS was significantly correlated with both grain yield ($r = 0.79$, $P < 0.01$) and TDM at maturity ($r = 0.92$, $P < 0.01$).

Differences in yield among genotypes, and their interactions with sowing dates, were significant on both soils (Table 6). On Vertisols ICPL 87 gave the best

Table 4. *Mean time to 50% flowering and maturity of extra short duration and short duration (ICPL 87) genotypes following normal (June) and delayed (August) sowings on Alfisols and Vertisols in the rainy seasons of 1988 and 1989*

	Days to 50% flowering				Days to maturity			
	June sowing		August sowing		June sowing		August sowing	
	Alfisol	Vertisol	Alfisol	Vertisol	Alfisol	Vertisol	Alfisol	Vertisol
ICPL 83015	62	69	58	62	107	109	95	97
ICPL 84023	58	64	55	62	102	102	95	97
ICPL 85037	63	71	64	70	107	115	104	104
ICPL 4	65	74	60	63	107	114	97	94
ICPL 87	74	82	67	73	129	144	109	110
SE		0.8				0.9		

Table 5. *Leaf area index (LAI) at 60 days after sowing (DAS), total above-ground recoverable dry matter accumulation ($t\ ha^{-1}$) at 60 days after sowing (TADM-60) and at maturity (TADM-M), and grain yield ($t\ ha^{-1}$) following normal and delayed sowings in three growing seasons (data are the means of genotypes grown in all three seasons)*

	1987 season		1988 season		1989 season		
	Normal	Delayed	Normal	Delayed	Normal	Delayed	SE
			Alfisols				
LAI	2.81	1.50	4.18	1.84	1.93	1.09	0.208
TADM-60	2.61	2.65	4.34	1.88	1.81	1.61	0.205
TADM-M	3.80	2.84	7.32	3.01	3.39	1.98	0.127
Yield	1.47	1.25	2.49	0.95	1.24	0.57	0.046
			Vertisols				
LAI			4.12	0.59	1.31	1.20	0.109
TADM-60			3.56	0.85	1.03	1.57	0.089
TADM-M			4.50	1.19	2.32	1.47	0.103
Yield			1.09	0.45	0.56	0.43	0.028

yields, especially from delayed sowings. On Alfisols, the grain yield of the extra short duration genotypes from normal sowings was greatest at 66 plants m^{-2}, whereas that of ICPL 87 was greater at 16 and 33 plants m^{-2} (Table 7). Similar but less marked effects of sowing rate on yield were seen after delayed sowing and on Vertisols.

DISCUSSION

The extra short duration genotypes matured within 95–115 days from both normal and delayed sowings. This roughly matches the calculated effective length of the cropping season on Alfisols (115 days) but is much shorter than that on

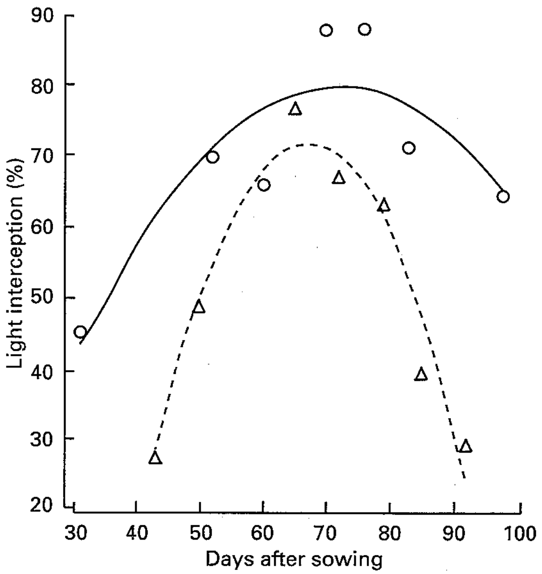

Fig. 2. Effect of sowing date (○, normal sowing; △, delayed sowing) on the mean light interception pattern of extra short duration pigeonpea genotypes during the crop growth period at the Alfisol site, 1989.

Table 6. *Grain yield (t ha^{-1}) of extra short duration genotypes and a short duration genotype (ICPL 87) following normal and delayed sowings on Alfisols and Vertisols in three growing seasons*

	1987 season		1988 season		1989 season	
Genotype	Normal	Delayed	Normal	Delayed	Normal	Delayed
			Alfisols			
ICPL 83015	1.47	1.42	2.76	1.03	1.62	0.59
ICPL 84023	1.62	1.21	2.27	0.92	1.14	0.67
ICPL 85037	1.23	1.21	2.39	0.85	1.08	0.55
ICPL 4	1.55	1.17	2.55	1.02	1.12	0.47
ICPL 87			1.87	0.87	1.28	0.67
SE	0.088		0.082		0.057	
			Vertisols			
ICPL 83015			1.19	0.37	0.53	0.26
ICPL 84023			1.18	0.46	0.41	0.36
ICPL 85037			0.86	0.51	0.39	0.47
ICPL 4			0.95	0.27	0.50	0.32
ICPL 87			1.26	0.64	0.99	0.70
SE			0.038		0.061	

Table 7. *Effect of plant population on the grain yield (t ha^{-1}) of extra short and short duration pigeonpea genotypes following normal and delayed sowings on Alfisols and Vertisols (mean of 1988 and 1989 seasons)*

Sowing time	Plant population (plants m^{-2})	Genotype ICPL 83015	ICPL 84023	ICPL 85037	ICPL 4	ICPL 87
		Alfisols				
Normal	16	1.97	1.46	1.46	1.68	1.67
	33	2.18	1.86	1.78	1.85	1.68
	66	2.41	1.81	1.96	1.98	1.38
Delayed	16	0.75	0.67	0.69	0.68	0.82
	33	0.82	0.89	0.73	0.77	0.83
	66	0.86	0.83	0.67	0.79	0.66
		Vertisols				
Normal	16	0.73	0.70	0.51	0.71	1.05
	33	0.89	0.83	0.63	0.74	1.18
	66	0.97	0.85	0.74	0.73	1.14
Delayed	16	0.22	0.30	0.38	0.21	0.52
	33	0.31	0.41	0.52	0.32	0.72
	66	0.42	0.52	0.58	0.37	0.81
SE				0.044		

Vertisols (175 days; Singh and Subba Reddy, 1988). Both short and medium duration genotypes are reported to grow well beyond the length of the cropping season on Alfisols and are therefore exposed to drought as they mature (ICRISAT, 1984). In our experiments the mean grain yield of the extra short duration genotypes compared favourably with that of ICPL 87 on Alfisols, even though they matured earlier. This is probably because their growing period matched the length of growing season better so that they escaped severe drought. The grain yields of medium duration genotypes grown in adjacent areas on Alfisols were only about 1 t ha^{-1}. Since there was little or no drought stress on the Vertisols, the extra short duration genotypes did not have the same advantage on these soils. Simulation studies in sorghum and soyabean have shown that early genotypes yield more than those maturing later if late drought reduces the yield of late maturing cultivars by at least 40% (Jordan *et al.*, 1983; Muchow and Sinclair, 1986).

The large differences in the grain yield of crops grown on different soil types, and across seasons within each soil type, reflect the instability of the extra short duration genotypes to various soil and climatic factors, particularly the amount and distribution of rainfall. They yielded best in the 1988 season when the rainfall was about 30% more than the long-term mean and relatively well distributed. In 1989, although there was a similar amount of rainfall, yields were significantly lower, perhaps because the rains occurred mainly in two peaks, which probably caused waterlogged conditions at critical times. Similarly in 1987, there was a drought during the reproductive phase of crops sown at the normal time and excess rainfall during other periods.

Medium-duration genotypes generally yield better on Vertisols than on Alfisols (ICRISAT, 1984). In contrast, in the present study, the grain yields of the extra short duration genotypes on Vertisols were about half those obtained over a slightly shorter period on Alfisols. The extra short duration genotypes flowered and matured earlier on the Alfisols than on the Vertisols, where they may have been affected by factors such as short-term waterlogging (Chauhan, 1987; Hodgson *et al.*, 1989) and poor nitrogen fixation (Kumar Rao and Sithanantham, 1989). It may be possible to achieve more stable yields by growing only those extra short duration genotypes that show tolerance to these adverse conditions, since the chances of a recovery if there is a check to growth are small because they mature so early.

Date of sowing also seems to have had a considerable effect on the adaptation of the extra short duration genotypes. Adaptability to variation in the time of sowing is essential under rainfed conditions as sowing time will vary with the time of the onset of rains. The reduced grain yield of the later sown crops was due to a reduction in leaf area index and the total above-ground dry matter accumulation and has been attributed mainly to changes in temperature and photoperiod and accompanying changes in solar radiation (Troedson *et al.*, 1990). In our studies, analysis of weather up to 60 DAS, when differences in growth between the two sowings became distinct, indicated that the crops experienced similar thermal regimes and incident radiation and that evaporative demand was only marginally less in the delayed sowings. Possibly soil moisture conditions, rather than the aerial environment, were responsible for the low yields of the extra short duration genotypes from delayed sowings.

The late-sown crop exhibited chlorotic symptoms and reduced growth even on the Alfisols. These symptoms are typical of pigeonpea that is subjected to waterlogging stress (Chauhan, 1987; Hodgson *et al.*, 1989). On both soils, the soil moisture content was higher at the time of the delayed sowings than at the time of the normal sowings. Oxygen concentration in these soils can decrease sharply during periods of excess moisture (Okada *et al.*, 1991). Although there was no standing water, seedlings of the later sown crops would still be exposed to short-term waterlogging if the rains had started before the time of sowing. But when the rains were delayed, as in 1987, soil moisture levels at the time of the delayed sowing were low and the yields from the two sowings were similar.

Drought at the end of the growing season is likely to reduce the yield of extra short duration genotypes when sowing is delayed. In two of the three seasons rainfall stopped at the normal time, and the late-sown extra short duration genotypes reached the reproductive stage at a time of receding soil moisture because they took a similar time to flower as those sown at the normal time. Increased tolerance to drought at the end of the growing season may therefore be very useful in improving the adaptation of extra short duration genotypes to delayed sowing. The significant genotype × sowing data interactions suggest that extra short duration genotypes differ in their adaptation to different times of sowing. ICPL 83015 performed particularly well when more water was available, as in the delayed sowings in 1987 and the normal sowings in 1988 and 1989.

On Alfisols, the extra short duration genotypes responded better than ICPL 87 to a higher plant population when sown at the normal time. This was expected because their reduced duration resulted in smaller plants. Surprisingly, no such response occurred in the delayed sowing, possibly because soil moisture was limiting. Under irrigated conditions, short-duration genotypes responded to increased plant populations up to 66 plants m^{-2} in delayed sowings (Chauhan *et al.*, 1987). Keatinge and Hughes (1981) have observed significant interactions between plant population and soil moisture status for yield in pigeonpea, but we found no effect of plant population on grain yield on Vertisols, probably because of their good water holding capacity.

Our results suggest that although extra short duration genotypes have the potential to yield well, realization of this potential depends on favourable soil moisture conditions throughout the growing period. In seasons when rainfall is poorly distributed, on Vertisols, and to some extent following delayed sowings, excess soil moisture appears to be a key factor in limiting yield. Water deficits may also be limiting after late sowings. Future work on extra short duration genotypes should therefore concentrate on overcoming these limitations, either by genetic improvements or by improved land and water management.

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