Pulse Physiology Progress Report 1979-1980

Part I Pigeonpea Physiology

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PIGEONPEA PHYSIOLOGY

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2.	Response of pigeonpea to environment and cultural practices	I. Madhusudana Rao	Y.L. Nene M.R. Rao M. Natarajan S. Sithanantham
3.	Source-sink relationships in pigeonpea	I. Madhusudana Rao	W. Reed J.V.D.K.K. Rao

CONTENTS

SUMMARY

I. Climate and soil:

The annual rainfall was just below average and the weather was particularly dry during the early growing period. There was heavy rainfall in September which adversely affected the September sown rabi pigeonpeas.

II. Analysis of growth and yield:

The main purpose of this experiment was to determine whether there was a differential partitioning of dry matter into reproductive and vegetative growth during the growth and development of two hybrids and their four parents. Neither the seed yields nor the total dry matter of the hybrids were significantly different from those of their best parents. The pattern of nutrient distribution was similar in all cases. Since no significant heterosis was expressed, an analysis of heterosis was not possible.

III. Screening for tolerance to soil salinity:

A preliminary field screening experiment has shown that by using a system of alternating rows of test and check lines, screening for salinity tolerance in a naturally saline field is feasible in spite of the lack of uniform levels of salinity.

IV. Screening for tolerance to waterlogging:

The screening of pigeonpea lines in artificially waterlogged fields using a system of alternating rows of test and check lines was found to be more reliable than screening in replicated plots.

V. Response to row-to-row and plant-to-plant spacing:

1. There was remarkably little difference in the mean yields of pigeonpeas over a range of population densities, from 33,000 to 666,000 plants/ha on both Vertisol and Alfisol. But although the yield remained

more or less constant, the weight of the stems and fallen leaves increased with increasing population density. Consequently, the harvest index decreased. The yield levels were generally higher on Alfisol than on Vertisol, as were the weights of the stems. By contrast, the weights of fallen leaves were greater on Vertisol than Alfisol.

2. As in previous years, the second harvest yields were much higher on Alfisol than on Vertisol.

3. Results from an additional experiment on the effect of sowing density on the growth and yield of pigeonpeas on Vertisol and Alfisol are in good agreement with those of the row-to-row and plant-to-plant spacing experiment.

VI. Rabi pigeonpea experiments:

1. As in the kharif season, the hybrids showed no significant heterosis for yield and dry matter production. The changes in the percentages of nitrogen, phosphorus, and potassium in the different parts of the plants were also similar in the parents and hybrids.

2. The phenology of 20 cultivars confirm the observations made in previous years that all the cultivars mature earlier when planted in the rabi season. The early cultivars performed significantly worse than the medium and late cultivars.

3. The yield of the late cultivar, T-7 was significantly poorer than the medium duration cultivar, C-11.

4. There was no significant response to foliar application of nutrients in terms of either growth or yield. But in response to irrigation, there was a large overall increase in growth and dry matter production, and the grain yields are approximately doubled. Irrigation also led to a significant increase in harvest index which at 50% was the highest we have ever observed in pigeonpeas.

I. INTRODUCTION

Meteorological and Soil Data

In this report, we present the results of work carried out between June 1979 and May 1980.

The meteorological data for 1979-80 collected at the ICRISAT agro-climatological observatory are shown in Fig. 1. The dates of sowing, flowering and harvest of the kharif and rabi pigeonpea crops are indicated in the figure. The rainfall during this year was just below average and was particularly dry during the early growing period (Table 1). There was very high rainfall in September which adversely affected the September sown rabi pigeonpeas.

Fertiliser was broadcast at the rate of 20 kg/ha N and 50 kg/ha P_2O_5 in the form of diammonium phosphate and incorporated before the fields were flattened or ridged. Sowings of the kharif experiments were carried out between 27.6.79 to 12.7.79. Two seeds per hill were sown by hand; 2-3 weeks after emergence the seedlings were thinned to one per hill. Sowings for the rabi experiments were done 20.9.79 and between 30.10.79 to 12.11.79. No fertiliser was applied.

On the BA-4 (Black Soil) and the B-10 (Black Soil) sites sorghum was grown the previous year. The soils were analysed at the time of sowing for pH, electrical conductivity, available nitrogen, and available phosphorus. Details are shown in Tables 2 and 3.

Hand weeding was carried out frequently to keep the plots as weed-free as possible. Periodic insecticidal sprays (0.35% endosulphan) and other plant protection measures (such as removal of blister beetles by hand) were carried out with the cooperation of the plant protection unit.

The spacing trial on red soil suffered due to water stress especially at high plant densities during the month of August, but because of the heavy rainfall in the month of September, the plants recovered to a large extent. However, as a result of this heavy rainfall two genotypes, ICP-7035 and MS-3A faced waterlogging problems and the crop turned pale yellow. Otherwise, the plant growth was normal in all the trials. In spite of the water stress in August, the yields were higher on red soil than on black soil.

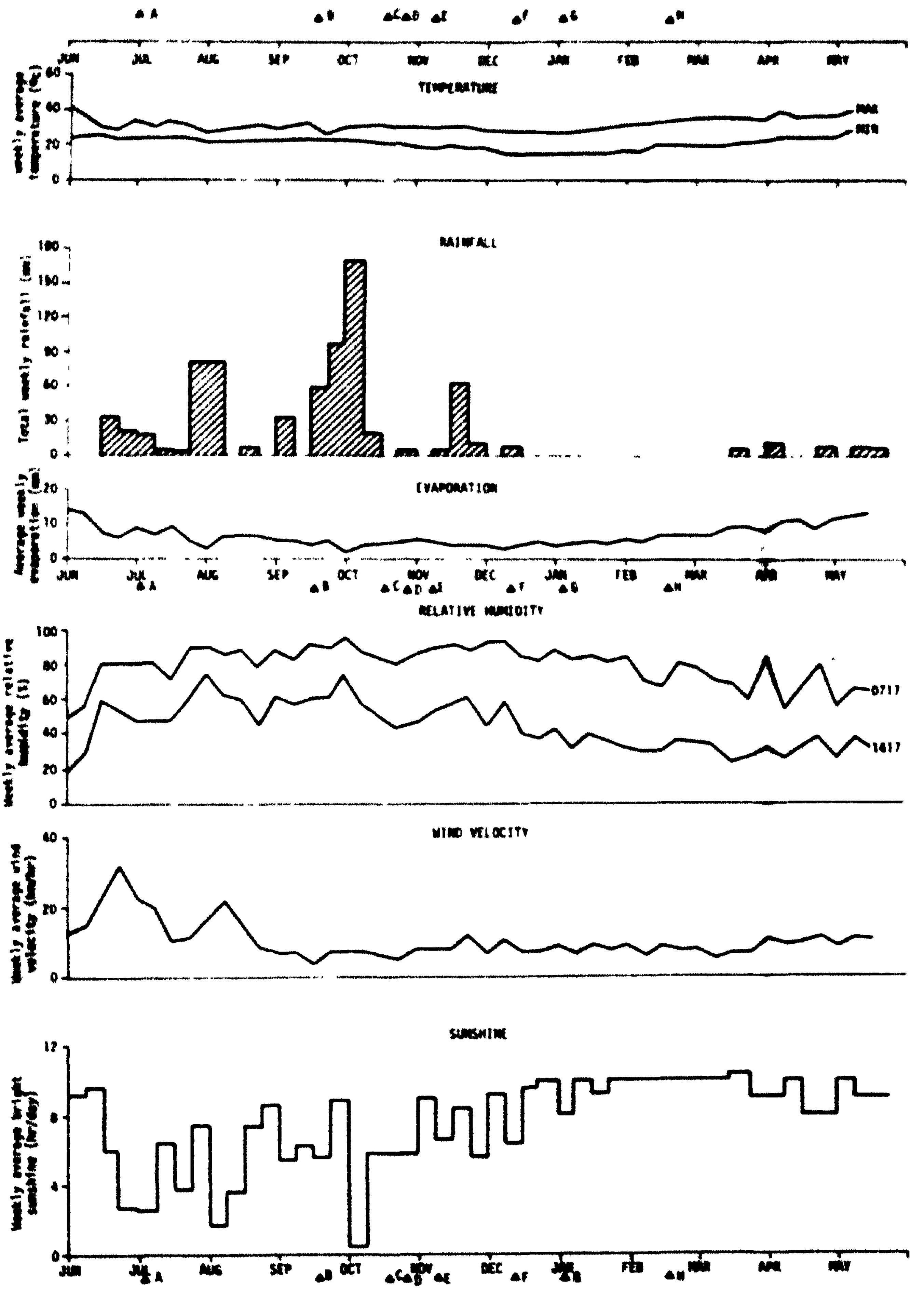

FIGURE 1. METEOROLOGICAL DATA (JUNE 1979 - MAY 1980).

A. Sowing rainy season crop.
B. Flowering (early cvs.).
C. Harvest (early cvs.).
D. Flowering (medium cvs.).
E. Sowing postrainy crop.
F. Harvest (medium cvs.).
G. Flowering (postrainy season cvs.).
H. Harvest (post rainy season crop).

Table 1. Summary of rainfall (mm) with departure from average (1940-70) for Hyderabad in parenthesis.

	MONTH												Total
	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	Apr.	May	
1979-80	58.6	104.0	120.3	328.3	21.0	79.1	0.0	0.0	4.0	8.6	6.6	18.1	748.6
	(-56.9)	(-67.5)	(-35.7)	(+147.3)	(-46.0)	(+55.6)	(-6.0)	(-5.5)	(-7.0)	(-3.9)	(-17.4)	(-8.4)	(-51.4)

Table 2. Soil analysis for the experimental sites used for pigeonpea studies in 1979-80.

Soil and field No.	Depth of soil (cm)	pH*	EC* (m.mhos/cm)	Available N (ppm)	Available P (ppm)
Black (Vertisol)	0-30	8.5	0.28	38	0.8
Field BA-4A	30-60	8.7	0.41	25	Traces
	60-90	8.8	0.63	30	Traces
	90-120	8.4	2.80	22	1.0
	120-150	8.2	1.85	11	2.2
Black (Vertisol)	0-30	8.4	0.42	33	3.8
Field BA-4B	30-60	8.6	1.10	27	3.6
	60-90	8.6	1.75	27	7.4
	90-120	8.7	3.80	22	5.6
	120-150	8.1	1.08	11	7.6
Black (Vertisol)	0-30	8.25	0.40	56	4.0
Field B-10	30-60	8.30	0.50	44	2.0
	60-90	8.30	0.72	42	1.0
Black (Vertisol)	0-30	8.0	2.5	38	6.0
Field BT-6	30-60	7.9	5.5	25	5.8
	60-90	8.3	2.6	22	1.4
	90-120	8.3	0.75	19	5.6
	120-150	8.3	3.20	14	1.0
Red (Alfisol)	0-30	7.9	0.25	52	13.0
Field R2-C	30-60	7.85	0.20	36	1.0
	60-90	7.60	0.22	22	Trace
Red (Alfisol)	0-30	7.60	<0.15	60	9.0
Field RA-28	30-60	7.60	<0.15	66	5.8
	60-90	7.15	<0.15	44	2.6
Paddy field	0-30	8.10	0.28	44	9.0
Block "A"	30-60	8.25	0.37	38	3.4
	60-90	8.65	0.55	27	5.8
	90-120	9.00	0.38	16	6.5
	120-150	8.70	0.28	13	4.6
Paddy field	0-30	8.25	0.28	51	15.0
Block "B"	30-60	8.40	0.45	36	13.0
	60-90	8.55	0.45	30	10.0
	90-120	8.80	0.50	25	4.0
	120-150	8.80	0.51	15	13.5
Paddy field	0-30	8.10	0.32	47	18.0
Block "C"	30-60	8.30	0.37	38	11.6
	60-90	8.45	0.45	33	1.0
	90-120	8.70	0.50	27	0.6
	120-150	8.80	0.50	22	Trace

* in 1:2 soil water ratio

Table 3. Soil analyses for the soil used for salinity studies in Brick chambers in 1979-80.

Treatment	Depth	Date of collection	pH	EC**	Available N (ppm)	Available P (ppm)
Control	0-15 cm	A*	7.90	0.40	56	6.1
		B*	8.02	0.43	54	3.3
,,	15-30 cm	A	7.85	0.38	50	3.9
		B	8.03	0.26	65	3.3
,,	30-45 cm	A	7.82	0.39	54	5.6
		B	8.03	0.27	70	6.7
,,	45-60 cm	A	8.05	0.67	39	3.4
		B	-	-	-	-
10 m.eq.	0-15 cm	A	7.62	0.80	59	2.1
		B	7.77	0.97	69	10.3
,,	15-30 cm	A	7.58	0.85	59	3.2
		B	7.83	0.70	77	6.3
,,	30-45 cm	A	7.43	0.87	53	4.43
		B	7.88	0.74	87	5.70
,,	45-60 cm	A	7.45	0.83	58	3.4
		B	-	-	-	-
20 m.eq.	0-15 cm	A	7.25	1.63	53	6.3
		B	7.70	2.62	64	8.3
,,	15-30 cm	A	7.38	1.39	52	3.3
		B	7.70	1.16	71	6.7
,,	30-45 cm	A	7.43	1.38	49	4.8
		B	7.77	1.19	85	6.7
,,	45-60 cm	A	7.45	1.39	53	3.5
		B	-	-	-	-

*A = 20-7-1979
*B = 4-1-1980

**in 1:2 soil water ratio

We have referred to our Pigeonpea Physiology Reports for 1974/5, 1975/6, 1976/7, 1977/8, and 1978/9 as PPR 1974/5, PPR 1975/6, PPR 1976/7, PPR 1977/8, and PPR 1978/9 respectively. We have also referred to the Chickpea Physiology reports (CPR) for these years. Copies of the available reports can be supplied on request.

This report is not a formal publication but a summary of work in progress. It is intended for limited circulation only and should not be cited.

II. ANALYSIS OF GROWTH AND YIELD

Introduction

Growth, yield and nutrient uptake in hybrids and their parents.

The objective of this analysis was to determine whether there was a differential partitioning of dry matter into reproductive and vegetative growth during the growth and development of two hybrids and their four parents.

Materials and methods

Two hybrids (MS-4A X C-11 and MS-3A X ICP-7035) developed in the breeding program and their four parents (MS-4A, C-11, MS-3A, and ICP-7035) were used for this study. The two hybrids and their four parents were grown in field BA-4A (Vertisol) on 75 cm ridges with a plant-to-plant, spacing of 30 cm in 4 replications of a randomized block design (plot size: 9X6 m).

Samples consisting of 5 adjacent plants were taken from 4 replicate plots and morphological characters and the dry weights of the component plant parts were recorded separately for each plant on the 25th day after sowing, and thereafter every twenty five days until maturity. The dried samples were ground to powder for analysis of N, P and K contents. Within each of the plots, permanent quadrates were established from which fallen leaves, pods, flowers etc., were collected throughout the latter part of the growth of the crop. The leaf area was measured with an automatic leaf area meter.

At harvest, yield and yield components, plant height and vegetative dry matter were measured.

Phenologies of the two hybrids and their four parents were shown in Table 4.

Results and discussion

Growth and development: The seasonal profile of dry matter distribution is shown for the two hybrids and their four parents in Figs. 2 and 3. The dry matter production was more in the pollen parent C-11 than its hybrid, and in the case of the other hybrid, the dry matter production

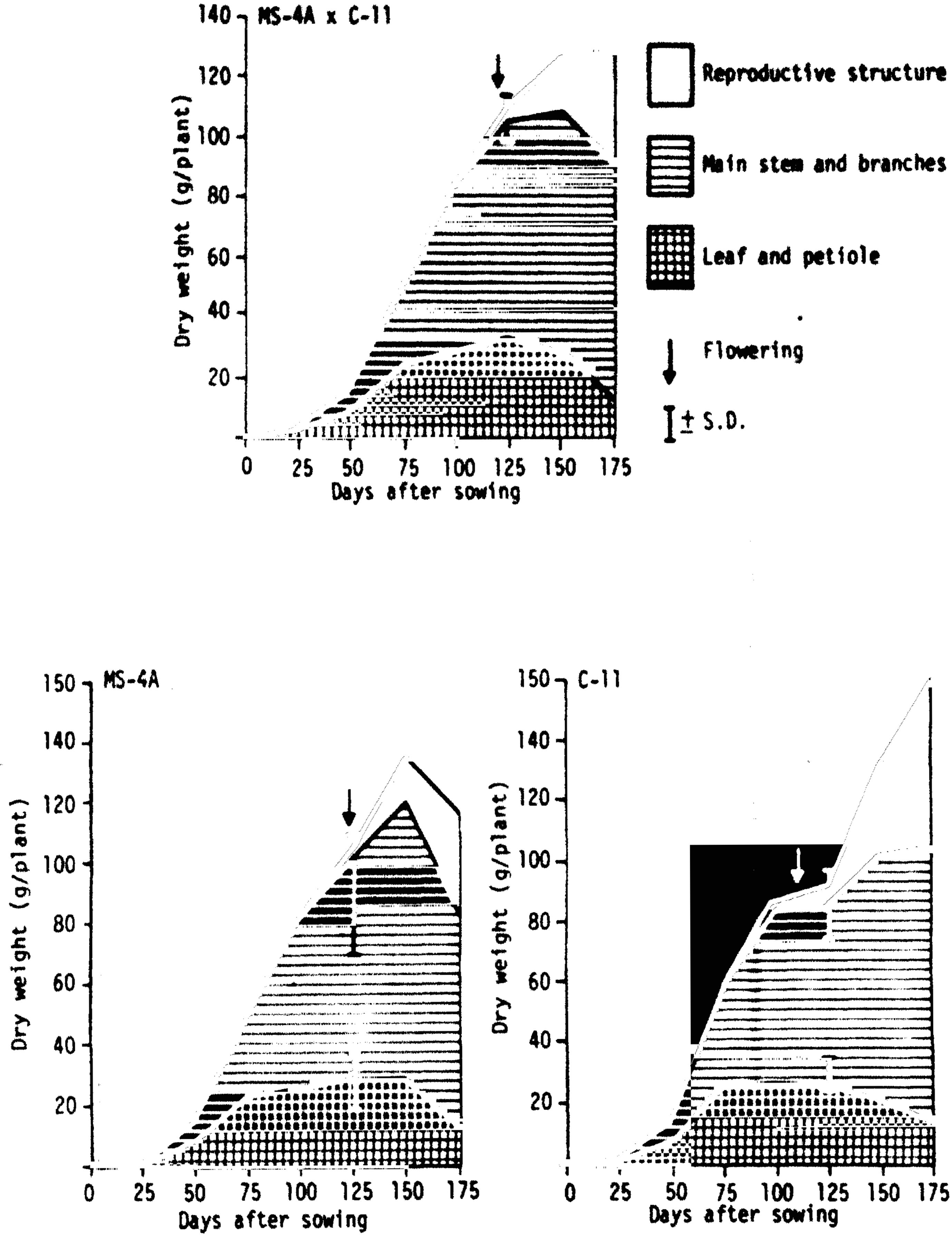

FIGURE 2. DRY MATTER DISTRIBUTION IN PIGEONPEA HYBRID AND PARENTS GROWN IN RAINY (KHARIF) SEASON 1979-80 ON VERTISOL AT ICRISAT CENTER.

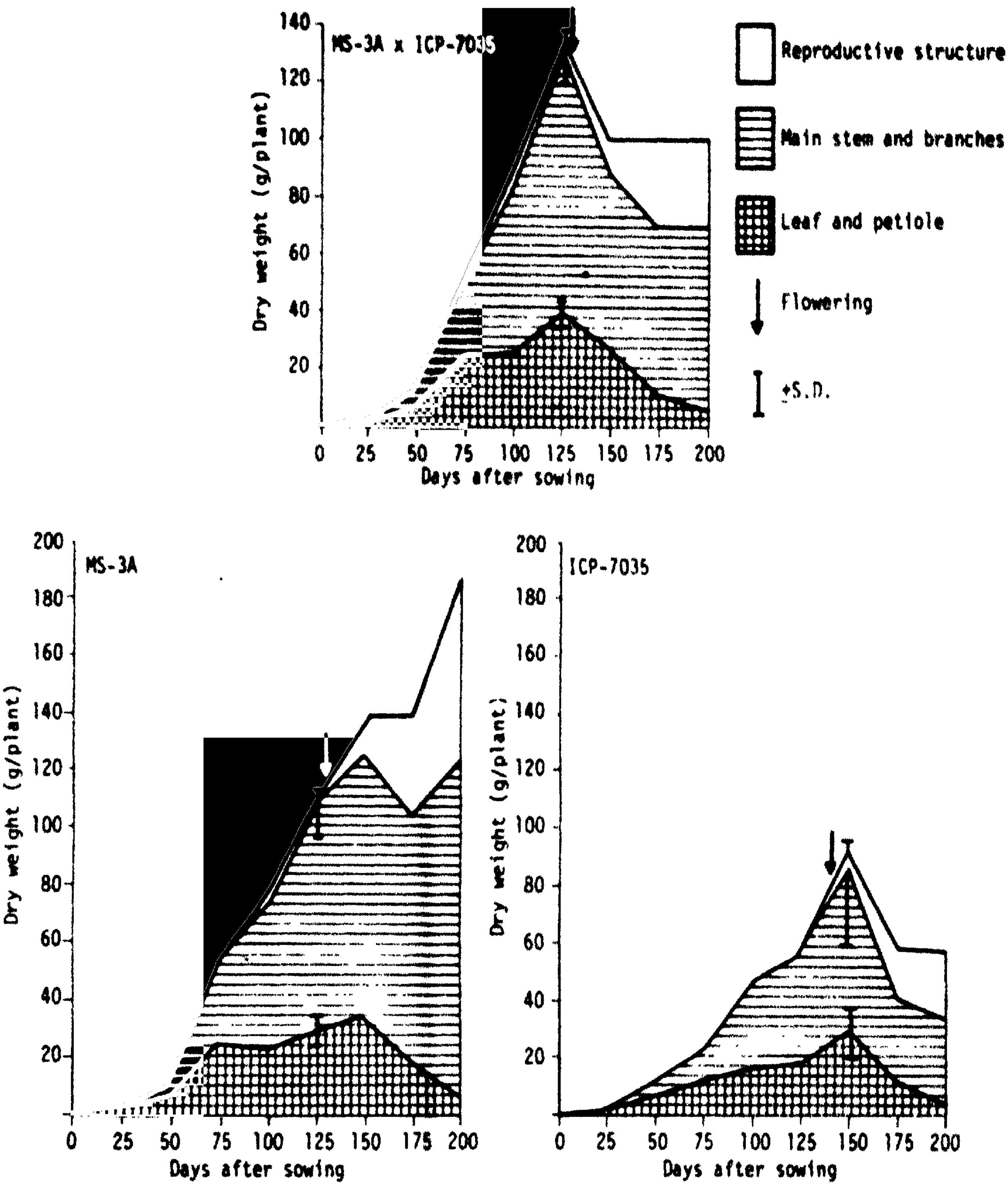

FIGURE 3. DRY MATTER DISTRIBUTION IN PIGEONPEA HYBRID AND PARENTS GROWN IN RAINY (KHARIF) SEASON 1979-80 ON VERTISOL AT ICRISAT CENTER.

Table 4. Phenology of two hybrids and four parents of pigeonpea grown on Vertisol at ICRISAT Center in rainy (kharif) season 1979.

Cultivars and hybrids	Date of sowing	Date of 50% flowering	Date of maturity	Date of harvest
C-11	27-6-79	28-10-79 (123)*	10-12-79 (167)	20-12-79
MS-4A	27-6-79	24-10-79 (119)	6-12-79 (163)	20-12-79
MS-4A X C-11	27-6-79	15-10-79 (110)	10-12-79 (167)	20-12-79
ICP-7035	27-6-79	15-11-79 (141)	10-1-80 (198)	11-1-80
MS-3A	27-6-79	1-11-79 (128)	26-12-79 (183)	11-1-80
MS-3A X ICP-7035	27-6-79	15-11-79 (142)	10-1-80 (198)	11-1-80

* Figures in parenthesis indicate number of days

Table 5. Comparison of several morphological traits at flowering of two hybrids and their four parents of pigeonpea grown in 1979 rainy season.

Plant characters	C-11	MS-4A	MS-4A X C-11	ICP-7035	MS-3A	MS-3A X ICP 7035	S.Em ±
Plant height (cm)	149.5	171.0	174.6	155.9	185.7	169.7	4.2
Total dry matter (g/plant)	103.8	122.1	127.7	108.6	128.7	152.9	6.2
No. of leaves/ plant	265.4	299.4	330.2	183.8	280.9	338.2	14.4
No. of leaf scars/plant	109.7	159.8	147.3	81.4	139.8	156.3	7.8
Leaf area/plant (cm^2)	4878	5114	6463	4413	5684	7109	315
Leaf area index	2.2	2.3	2.9	2.0	2.5	3.2	0.1

was more in the male sterile stock, MS-3A. The dry matter distribution in leaves was almost same in the parents as well as the hybrids. But in the case of main stem and branches, there were differences between hybrids and their best parents. These differences may be due to the variation in the subsamples.

The seasonal profile of leaf area index (LAI) is shown for the two hybrids and their parents in Fig. 4. The LAIs achieved in hybrids were significantly higher than their best parents at flowering (Fig. 4 and Table 5) LAI in the case of MS-4AXC-11 was maintained near the maximum for longer period than the MS-3AXICP-7035. As a result of this, the leaf area duration was greater in MS-4AXC-11. Among the parents, C-11 and MS-3A had higher leaf area duration similar to that of higher dry matter production.

Other morphological characteristics at flowering and at maturity are shown in Tables 5 and 6.

Seed yield: The seed yield data from plot harvest are shown in Table 7. Neither the seed yields nor the total dry matter of the hybrids were significantly different from those of their best parents.

The main purpose of this experiment was to analyse the heterosis for the growth and yield of the hybrids. But since no significant heterosis was expressed, this analysis is not possible.

More promissing hybrids than the two used in this study have been developed in the Pigeonpea Breeding Program; studies on one of them and its parents are being carried out at present.

Nutrient content of plant parts: The changes in the percentages of nitrogen, phosphorus, and potassium in the different parts of the plants were also similar in the parents and the hybrids. One set of data is shown in Fig. 5. The pattern was similar to that previously observed in pigeonpea grown in rainy season (PPR 1976/7).

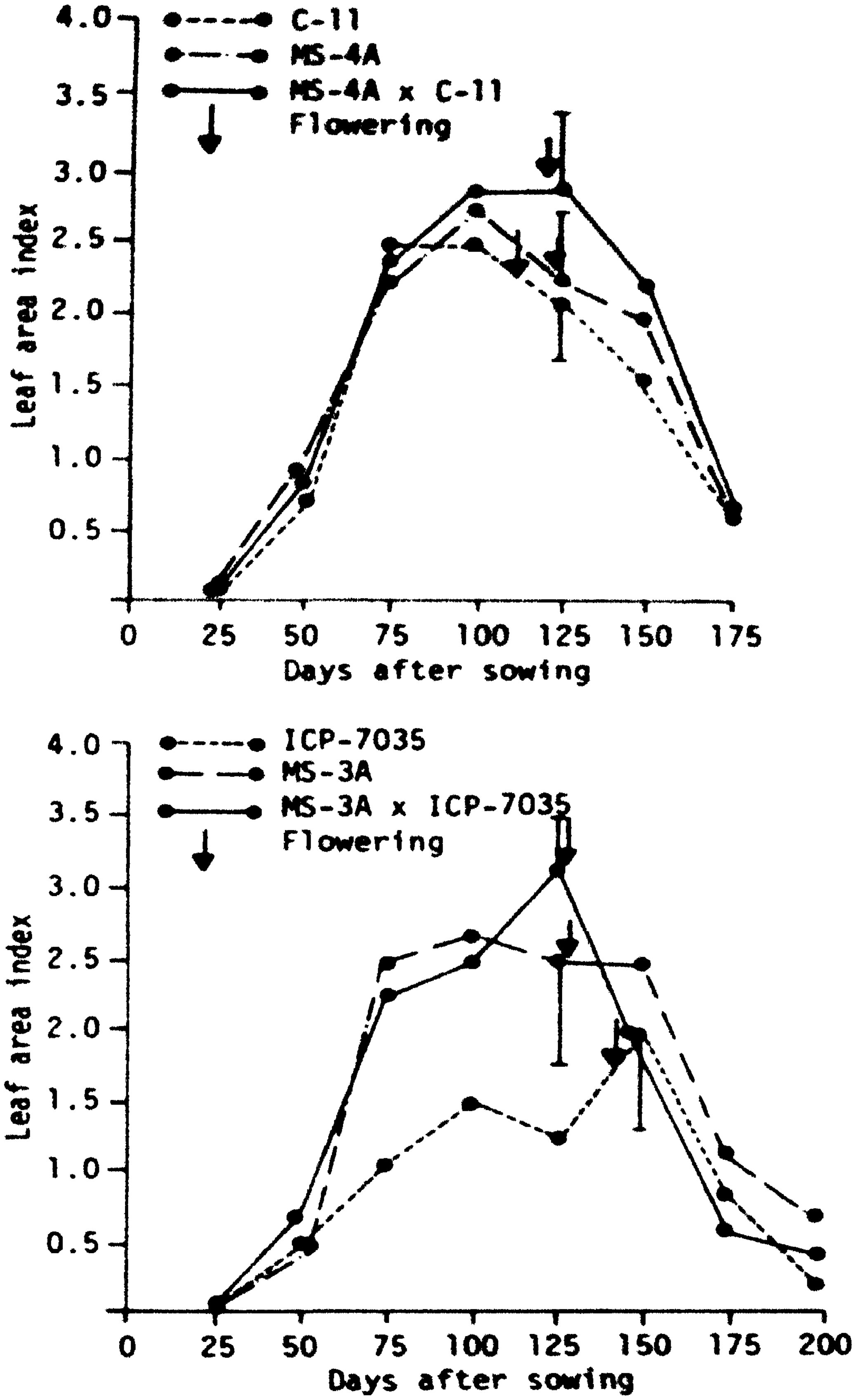

FIGURE 4. LEAF AREA INDEX OF PIGEONPEA HYBRIDS AND THEIR PARENTS GROWN IN RAINY (KHARIF) SEASON 1979-80 IN A VERTISOL AT ICRISAT CENTER.

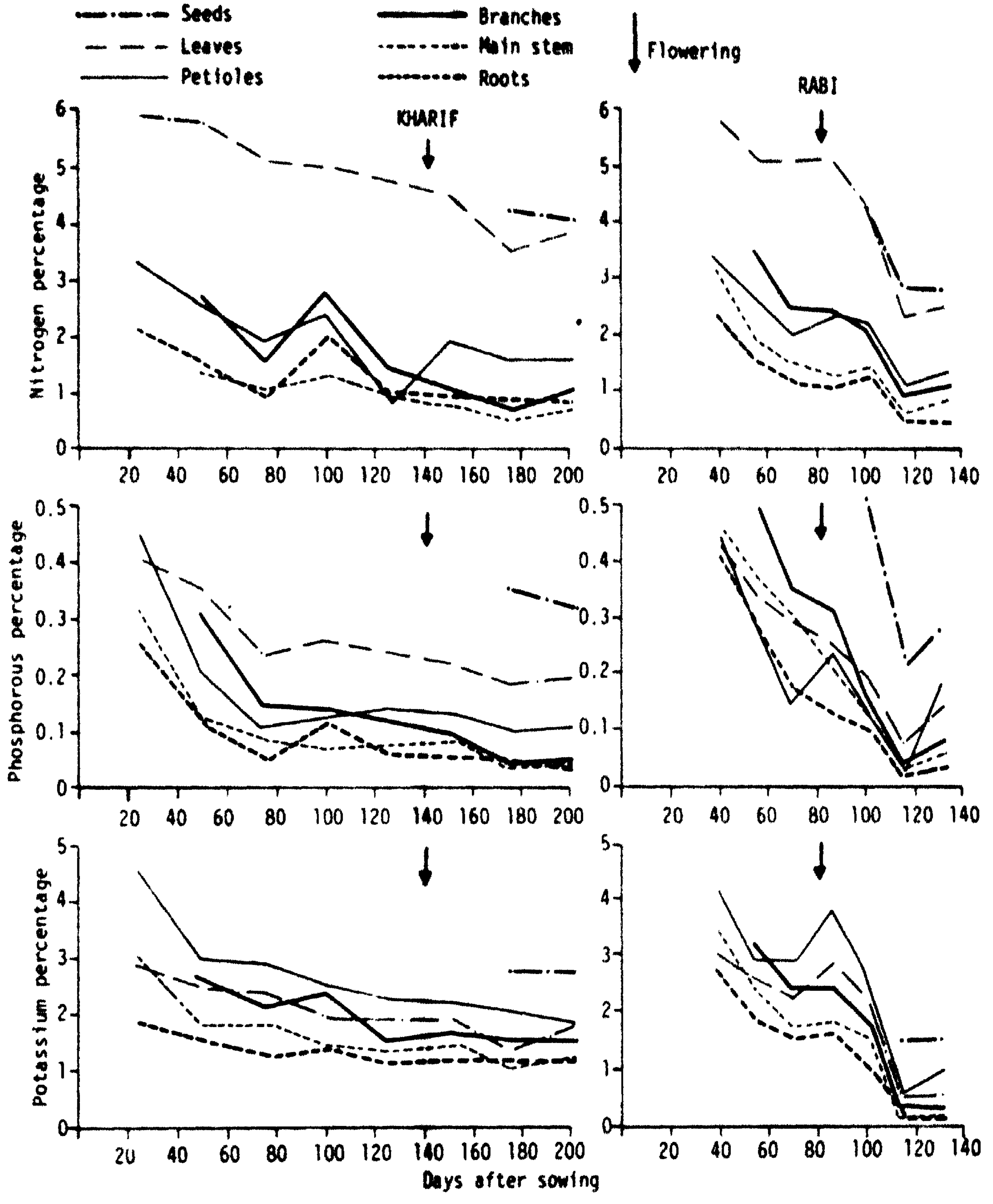

FIGURE 5. NITROGEN, PHOSPHOROUS, AND POTASSIUM PERCENTAGES IN PLANT PARTS OF THE CV.ICP-7035 GROWN IN RAINY (KHARIF) AND POST-RAINY (RABI) SEASONS 1979 AT ICRISAT CENTER.

Table 6. Comparison of several morphological traits at maturity of two hybrids and their four parents of pigeonpea grown in 1979 rainy season.

Plant characters	C-11	MS-4A	MS-4A X C-11	ICP-7035	MS-3A	MS-3A X ICP-7035	S.Em ±
Plant height (cm)	173.9	172.1	170.7	132.6	178.2	156.2	5.5
Total dry matter (of plant)	170.9	133.6	147.7	70.1	161.4	118.3	13.6
No. of leaves/ plant	171.6	170.4	172.9	47.7	203.9	98.6	18.0
No. of leaf scars/plant	288.4	289.8	323.8	150.2	407.7	329.1	19.7
Leaf area/ plant (cm^2)	1563	1531	1588	607	1693	938	148
Leaf area index	0.7	0.7	0.7	0.3	0.7	0.4	0.1
Total primary branches/plant	19.0	26.1	28.1	12.6	21.1	19.4	2.1

Table 7. Total dry matter, seed yield and yield components of two hybrids and their four parents of pigeonpea grown on Vertisol at ICRISAT Center, rainy (kharif) season 1979.

Plant character	C-11	MS-4A	MS-4A X C-11	ICP-7035	MS-3A	MS-3A X 7035	S.Em ±	LSD (5%)
Total dry matter (kg/ha)	6192.9	5771.3	6426.2	3131.4	5593.7	4980.2	512.7	1544.9
Total dry matter (g/plant)	138.9	130.1	141.5	73.5	129.9	116.5	12.7	38.1
Yield (kg/ha)	1389.8	976.0	1257.4	756.3	1162.4	1067.7	119.0	358.6
Yield (g/plant)	31.2	22.0	27.7	17.8	27.0	25.0	2.9	NS
Harvest index (%)	20.7	17.1	19.8	23.0	20.9	21.5	1.6	NS
Total fallen leaves dry wt. (kg/ha)	1360.3	1476.8	2139.0	730.7	1419.7	1557.0	212.7	641
Corrected total dry wt. (kg/ha)	7553.2	7248.0	8565.2	3837.1	7013.4	6537.2	529.8	1596.3
Corrected harvest index (%)	18.2	13.5	14.7	18.8	16.6	16.2	1.1	3.4
100-seed weight (g)	9.7	7.3	8.0	16.3	7.1	7.9	0.4	1.3
Seed No./pod	2.6	2.7	2.6	3.5	3.0	2.8	0.2	NS
Pod No./plant	129.0	132.8	110.8	29.9	110.1	120.5	17.8	53.7

III. SCREENING FOR TOLERANCE TO SOIL SALINITY

Introduction

In preliminary experiments we have shown that there are marked differences among pigeonpea cultivars in their tolerance to soil salinity (PPR 1977/8; 1978/9). This year further experiments were carried out both in artificially salinized soil and in a naturally saline field in an attempt to develop simple and effective screening procedure for the identification of salinity tolerant cultivars.

Materials and methods

Experiment with artificially salinized soil:

For this study the large brick chambers described in PPR 1977/8 were used. Salts were added to the soil (a Vertisol) in the ratio of 7 m. eq. Nacl: 1 m.eq. Na_2 So_4: 2 m. eq. $CaCl_2$ and mixed thoroughly to produce two levels of soil salinity, 10 and 20 m. eq./kg soil. This soil was placed in the brick chambers. Samples taken from the chambers were analysed for pH and electrical conductivity (Table 3). Soil to which no salts have been added was used as a control. Each treatment was replicated in these chambers Seeds of two putatively tolerant cultivars (C-11 and ICP-3786), and two putatively susceptaible cultivars (JA-275 and HY-3C) were sown in each chamber in rows each 1 m long and 20 cm apart. The four cultivars were randomized among the four row positions available in each chamber.

To avoid the leaching of salts by rain, a canopy structure was erected over the chambers, and covered with polythene sheeting.

Field experiment:

The field screening was carried out in a naturally saline field, BT-6A. Analysis of pooled samples from six places in the field showed that in the upper 30 cms the electrical conductivity was 2.5 m.mhos/cm (Table 2). A total of 47 lines were tested; 30 advanced lines of breeders' material, 11 cultivars and 6 species of *Atylosia*. The screening method adopted was similar to that used by pathologists in sick plots; a row of the tolerant check (cv. C-11), and a row of the susceptible check (cv. HY-3C) were grown on either side of an unreplicated row of the line to be tested. The rows were 40 m long, 37.5 cm apart and the plant-to-plant spacing within the rows was 10 cm. Periodic observations were made on the survival of plants in each row.

Results and discussion

Experiment with artificially salinized soil:

The time course of percentage plant survivals for four pigeonpea cultivars grown in salt treated soils in brick chambers is shown in Table 8. At 20 m. eq./kg soil treatment, all cultivars showed 100 percent mortality, and at 10 m. eq./kg soil treatment, there was little difference between the putative tolerant cultivars (C-11 and ICP-3786) and the susceptible types (JA-275 and HY-3C) in their survival. These results indicate that it may be better to test at 15 m. eq./kg soil treatment to obtain a more differential reaction between tolerant and susceptible genotypes.

Field experiment:

The field was far from uniform in its level of salinity, but the method adopted enabled the test lines to be compared with immediately adjacent tolerant and susceptible checks. The checks showed a very satisfactory differential response, with a much lower rate of survival in the susceptible than in the tolerant check. The survival of most of the lines tested was intermediate between those of the tolerant and susceptible checks, but 9 out of the 47 tested survived better than the tolerant check. These are listed in Table 9.

This preliminary experiment has shown that by using a system of alternating rows of test and check lines, screening for salinity tolerance in the field is feasible in spite of the lack of uniform levels of salinity. In future trials, a replicated design will be used and cultivars identified as tolerant to soil salinity by this method will then be investigated further under more controlled conditions in artificially salinized conditions.

Table 8. Time course of plant survival (in percentages) for four pigeonpea cultivars grown in artificially salinized soils (1979-80)

Cultivar	Treatment	21 days	42 days	63 days	84 days	120 days	133 days
C-11	Control	100	93	93	93	87	87
	10 m.eq/kg. soil	100	93	87	87	87	87
	20 m.eq/kg. soil	54	0	0	0	0	0
ICP-3786	Control	100	100	100	100	100	100
	10 m.eq/kg. soil	100	93	93	93	93	93
	20 m.eq/kg. soil	70	13	13	13	0	0
JA-275	Control	100	100	100	100	92	85
	10 m.eq/kg. soil	96	87	87	87	87	80
	20 m.eq/kg. soil	76	0	0	0	0	0
HY-3C	Control	100	100	100	100	100	100
	10 m.eq/kg. soil	100	93	87	87	73	73
	20 m.eq/kg. soil	87	0	0	0	0	0

Table 9. List of pigeonpea lines more tolerant to soil salinity than the tolerant check, cv. C-11

Entry	Pedigree
4043	ICP-7118-95 ⊗ -1 ⊗ -B ⊗ -B
4315	ICP-7182-74 ⊗ -2 ⊗ -B ⊗ -B
4404	ICP-7623-20 ⊗ -2 ⊗ -B ⊗ -B
4411	ICP-7623-36 ⊗ -1 ⊗ -B ⊗ -B
4428	ICP-7623-77 ⊗ -1 ⊗ -B ⊗ -B
4435	ICP-7623-115 ⊗ -1 ⊗ -B ⊗ -B
4529	ICP-7035-16 ⊗ -1 ⊗ -1 ⊗ -B ⊗ -B
ST-1	
Atylosia scaraboides	

IV. SCREENING FOR TOLERANCE TO WATERLOGGING

Introduction

Differences have been observed under field conditions among pigeonpea cultivars in their tolerance to waterlogging (PPR 1977/8; 1978/9). Stands of waterlogging- susceptaible cultivars are seriously damaged on poorly drained soils followed heavy storms during the rainy season. Attempts have been continued to develop screening techniques for identifying tolerant and susceptible cultivars using field plots which are deliberately waterlogged for definite periods.

Materials and methods

The trials were conducted in elevated former paddy field in which drainage systems had been installed. The outlet from tile drains of each field has a stopcock so that the duration of waterlogging can be readily controlled. Each plot was made flat and divided into small diked sub-plots for better control of the water level.

Replicated trial:

Four cultivars, two putatively tolerant (BDN-1 and No.148) and two putatively susceptible (HY-3C and ICP-6997) cultivars were planted in blocks 'A' and 'B' of the paddy field on 10-7-79 and 25-7-79 respectively to test the feasibility of screening for tolerance to waterlogging in the field during kharif season. Seeds were sown with 50 cm rows apart with 20 cm plant-to-plant spacing in four replications (plot size: 5x11 m) of a randomized block design.

Block 'A' was waterlogged for 4 days at 40 days after sowing and block 'B' was waterlogged for 4 days at 60 days after sowing. Counts were made on 7th day for block 'A' and 19th day for block 'B' after drainage to determine the survival percentage of plants.

Non-replicated trial with tolerant and susceptible checks:

A total of 121 advanced generation lines of different maturity groups were planted in block 'C' without any replications on 25-7-79 in 10 m long rows of 50 cm apart with 20 cm plant-to-plant spacing by using tolerant and susceptible check lines side by side. The block was waterlogged for 4 days at 40 days after sowing. Counts were made 7 days after treatment to determine the survival percentage of plants.

Results and discussion

The effect of controlled waterlogging for 4 days on the percentage mortality of two putatively tolernt (BDN-1 and No.148) and two putatively susceptible cultivars (HY-3C and ICP-6997) at 40 and 60 days after sowing is shown in Table 10. There was no significant difference between putatively tolerant and putatively susceptible cultivars at the earlier time of waterlogging; but on the second occasion there was significantly more mortality in the susceptible cv. HY-3C (Table 10). The coefficient of variation was very high, and this method seems unreliable, primarily because of the difficulty of establishing uniform waterlogging and drainage conditions within and between plots.

This difficulty was overcome to some extent in the trial where each test line was planted in a single row with a row of the tolerant and the susceptible check on either side. The survival of the plants in the test line could then be compared directly with the survival of the adjacent tolerant and susceptible checks.

In most cases, plants of the tolerant check did indeed survives better than the nearby susceptible checks. In the trial as a whole, the overall average survival of the tolerant check was 83%, of the susceptible check 61% and of the test lines 73%.

A list of the lines which showed a fairly high degree of tolerance to waterlogging and of those which were particularly susceptible is given in Table 11.

Further screening of breeders' material is in progress, using a modification of this technique with replications of the test lines.

Table 10. Effect of controlled waterlogging for 4 days at 40 or 60 days after sowing on the percentage mortality of 4 pigeonpea cultivars (kharif 1979).

Cultivars	Percentage mortality	
	Waterlogging at 40 days	Waterlogging at 60 days
BDN-1	73	10
No.148	61	13
HY-3C	67	63
ICP-6997	67	7
CV% (on the basis of transformed data)	23	38
LSD	NS	16

Table 11. List of pigeonpea lines tolerant and susceptible to waterlogging

TOLERANT

(more tolerant than the tolerant check, cv. BDN-1)

Entry No.	Pedigree	Generation
74068	(PrabhatxBaigani) NDT1-B-14-B-HIIDT 2-B-B	F 9
74174	(ICP-7035xUPAS-120)-NDT1B-1-2-HIIDT2-B-B	F 8
ICPL-9	(JA-275xPusa ageti)-14-1-B-1-B-II DTB-B	F 10
ICPL-95		F 7
ICPL-81	6971 (UPAS-120)-41-6-5-2-B-B-HB-B	
ICPL-88	74078 (pant A-2xBaigani)-12-B-1-2-HII NDT 10-B-B	
ICPL-113		F 8
74054-1-3-S5VIII NDT-B	SMV resistant line	
74240-2-5-VI-NDT 5-B	Medium Mat. Adv. Lines	
73067-53-2-VI NDT 3-B		F 6
ICP-3786		

SUSCEPTIBLE

(more susceptible than the susceptible check, cv. HY-3C)

3868-1 (W)-28-BII-1-III NDT 6-B-B		F 3
74146	(PrabhatxICP-7035) NDT II B-18-1-HIV. NDTI-B-B	F 8
ICPL-109		F 8
ICPL-86	74092 (ICP-6997xPrabhat) DTB-15-1-HTDT1-B-B	
ICPL-24		F 9
74332-80-VI NDT2-B		F 5
ICP-3193-12		

V. RESPONSE TO ROW-TO-ROW AND PLANT-TO-PLANT SPACING

In a preliminary trial carried out last year to investigate the response of pigeonpeas to within row spacing when they were planted at wide row-to-row spacing, there was a significant increase in yield with increasing plant density. The early cv. T-21 gave the highest yield at the closest within row spacing tested (2.5 cm); the medium cv. C-11 yielded significantly more at 5 cm and 2.5 cm spacings than at spacings of 20 cm or more; the late cv. NP(WR)-15 showed no significant difference in yield with spacings between 20 and 2.5 cm, but over this range the yield was more than with spacings of 30 cm and 50 cm (PPR 1978/9 Tables 31-33, Fig. 17).

This year more detailed spacing experiments were carried out on both Alfisol and Vertisol, using two cultivars on each, with all combinations of three row-to-row spacings (30, 60 and 120 cm) and three plant-to-plant spacings (2.5, 10, and 25 cm).

Materials and methods

Two medium duration cultivars (C-11 and BDN-1) were planted on 28 June 1979 on a Vertisol in field (BA-4A). One early (T-21) and one medium (BDN-1) duration cultivar were planted on 9 July 1979 on an Alfisol in field RA-29. The design of the experiment was a split-plot with cultivars as main plot treatments and spacings as sub-plot treatments in three replicates (sub-plot size: 9x6 M). The spacing treatments were varying row-to-row (30, 60, and 120 cm) and plant-to-plant (2.5, 10, and 25 cm) spacings to give a range of eight different populations (33,000 to 1,333,000 plants/ha) with nine combinations of spacing (Table 12). The actual populations at the time of harvest were considerably lower than the populations planted at the highest densities on Alfisol (Table 12) as a result of plant mortality due to water stress in the early stages of growth.

The first flush of pods in the early cultivar, T-21 were to a large extent damaged by the pod borer attack since these plants were not protected with insecticide sprays, owing to a labour strike during this period. However, the plants compensated for this damage by going on to produce a second flush of pods. Yield data for this second flush were collected and were analysed statistically together with the data for the normal first yield of cv. BDN-1. The plants in the sub-plots of cvs. BDN-1 and C-11 were left standing in the field after the harvest of the first flush (by hand picking of pods) to go on to produce a second flush of pods. Yield data for this second flush were collected and were statistically analysed.

Table 12. Summary of treatments and methods for two spacing trials at ICRISAT Center (1979-80).

Spacing	Planting geometry	Plant population (thousands/hectare)				
		Planned	Final			
			Vertisol		Alfisol	
			BDN-1	C-11	BDN-1	T-21
30 X 2.5	12:1	1333	1002	1015	777	746
30 X 10	3:1	333	317	322	277	263
30 X 25	1.2:1	133	126	127	126	114
60 X 2.5	24:1	666	563	526	458	411
60 X 10	6:1	166	165	164	140	156
60 X 25	2.4:1	66	65	65	63	63
120 X 2.5	48:1	333	270	269	226	281
120 X 10	12:1	83	81	82	73	74
120 X 25	4.8:1	33	33	33	31	31

The phenology of the cultivars was as follows:

Soil	Cultivar	Date of sowing	Date of 50% flowering	Date of maturity		Date of harvest
				First Flush	Second Flush	
Vertisol	C-11	29-6-79	15-10-79	12-12-79	14-3-80	27-3-80
	BDN-1	29-6-79	14-10-79	12-12-79	14-3-80	28-3-80
Alfisol	T-21	12-7-79	8-9-79	10-10-79	28-12-79	3-1-80
	BDN-1	12-7-79	5-10-79	20-12-79	6-3-80	11-3-80

Results and discussion

Vertisol experiment:

On the Vertisol, the yields of plants in rows 30 cm apart were lower at a plant-to-plant spacing of 2.5 cm than at 10 and 25 cms (Table 13). This effect was statistically significant in the mean data from the two cultivars. These results show that the highest population density of 1,333,000 plants/ha was super-optimal. However, at the lower densities, there were no significant differences between the mean yields, indicating a considerable plasticity of the plants over a wide range, from 33,000 to 666,000 plants/ha.

Last year, cv. C-11 planted in rows 150 cm apart gave a significantly higher yield with 2.5 cm than 20 cm within row spacing (PPR 1978/9, Table 32). A similar result was obtained this year in the same cultivar planted in rows 120 cm apart (Table 13). However, in cv. BDN-1 there was no significant difference in yield at different within-row spacings at this wide row-to-row spacing.

The dry weight of the stems was lowest at the lowest population density, and generally increased with closer within row spacing and with closer row-to-row spacings (Fig. 6). A similar increase occured in the weight of fallen leaves (Fig. 6).

The harvest index was highest at the lowest population density (Fig. 8). This result, taken together with data for dry weight of stems shown in Fig. 6, indicates that although at the higher population densities

Table 13. Mean yields of cultivars grown at different row-to-row and plant-to-plant spacings on a Vertisol (1979-80).

Plant-to-plant spacing (cm)	30 cm			60 cm			120 cm			Plant-to-plant spacing means
	C-11	BDN-1	Mean	C-11	BDN-1	Mean	C-11	BDN-1	Mean	
2.5	857	944	900	979	1159	1069	1132	1169	1150	1040
10	1089	1101	1095	1014	1153	1083	1035	1088	1061	1080
25	998	1204	1101	905	1136	1020	934	1103	1018	1046
Mean	981	1083	1032	966	1149	1057	1034	1076	1076	

Effect	L.S.D (P=0.05)
Row-to-row spacing	NS
Plant-to-spacing	NS
Row spacing at the same level of plant spacing	182
Row spacing within cultivars	NS

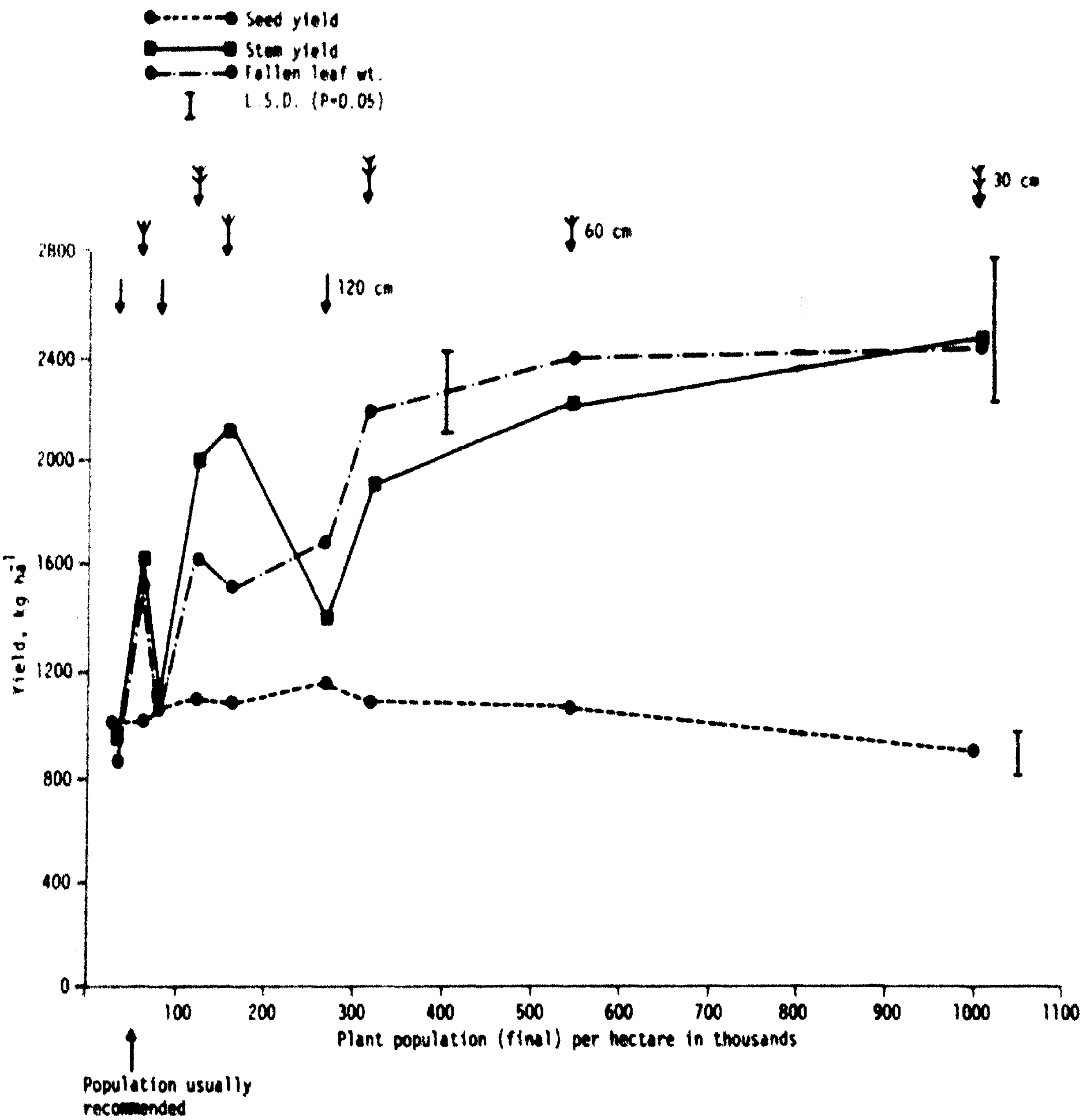

FIGURE 6. EFFECT OF PLANT POPULATION ON YIELDS OF PIGEONPEA GROWN ON VERTISOL (MEANS FOR CVS.BDN-1 AND C-11) IN 1979 RAINY SEASON.

the dry weight of stems increased, the greater plant-to-plant competition resulted in less of it being partitioned into seeds. This is in agreement with results obtained with a range of different cultivars in previous years (PPR 1975/6, Figs. 33-35; PPR 1976/7, Fig. 23).

There was no significant effect of spacing on 100 seed weight, but the seed number per pod was significantly reduced with closer row-to-row and plant-to-plant spacing.

Alfisol experiment:

The growth and yield of the cv. BDN-1 was considerably greater on the Alfisol than the Vertisol. The total dry matter produced on the former was 6227 kg/ha, compared with 4819 kg/ha on the Vertisol; and the yields were 1315 kg/ha and 1118 kg/ha respectively.

As on the Vertisol, the plants showed a very considerable plasticity in response to spacing, and the yields were similar over the whole range of population densities (Table 14). There was a tendency for the yield to fall off at the lowest planting density in the early cv. T-21, but this was not statistically significant.

The one exceptional feature of these results is that cv. BDN-1 produced a considerably higher yield at a spacing of 60 X 10 cm than at any other spacing. The population density of 166,000 plants/ha was similar to that of the 30 X 25 cm spacing (133,000 plants/ha), and yet the latter showed no sign of an elevated yield. Nor was any comparable response observed in cv. T-21, or in cv. BDN-1 itself on Vertisol (Table 13). But although it would be tempting to dismiss this result as a random variation, a very similar increase was observed in the experiment reported in the following section with a spacing of 50 X 20 cm on Alfisol; it therefore seems likely that under these conditions a row spacing of around 60 cm and plant-to-plant spacing of around 15 cm may be optimal.

As on the Vertisol, the dry weights of the stems and fallen leaves were lowest at the lowest population density and increased at closer within-row and between-row spacings (Fig. 7).

The harvest indices were generally higher on Alfisol than Vertisol, but showed the same pattern of decline in response to increasing competition between the plants (Fig. 8).

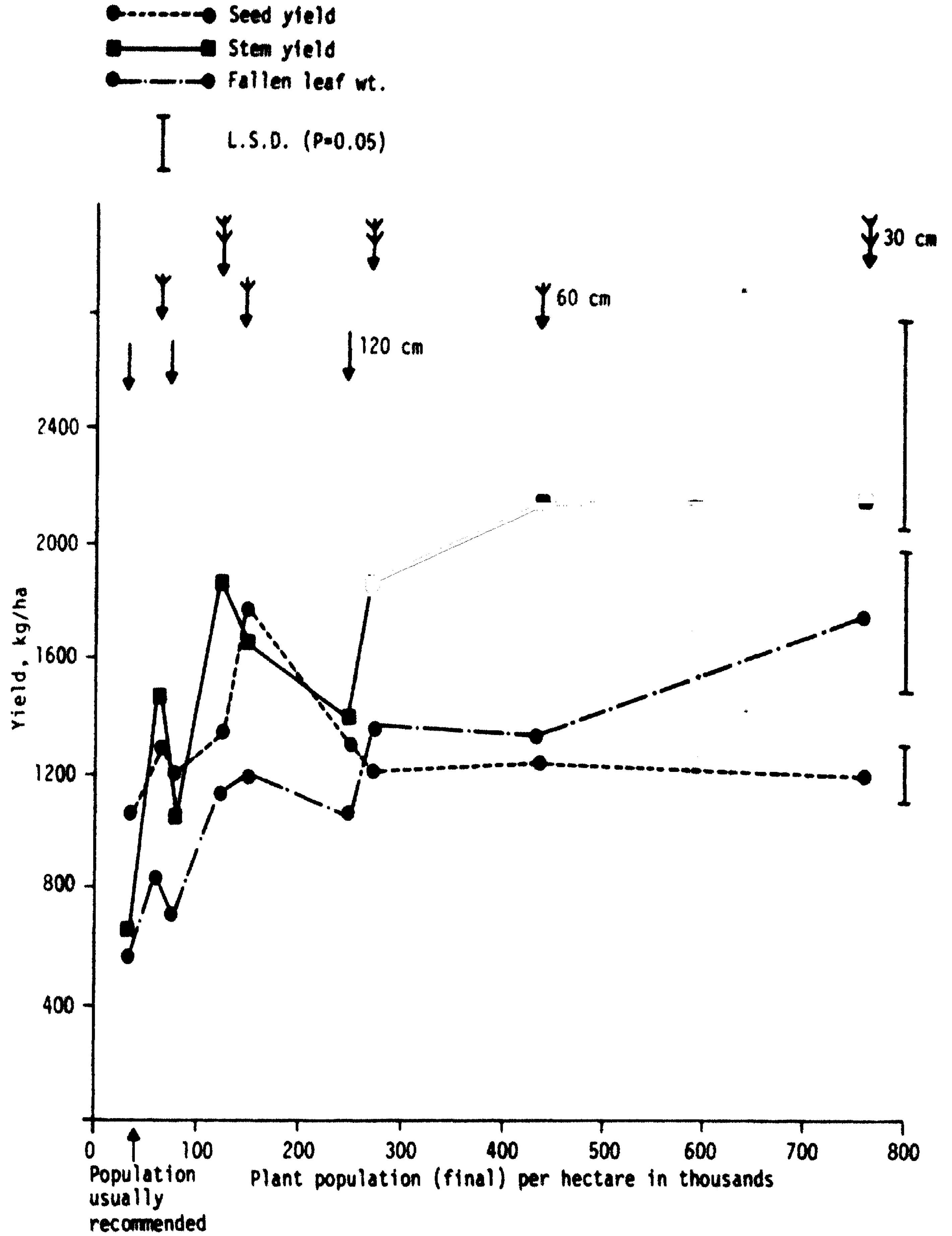

FIGURE 7. EFFECT OF PLANT POPULATION ON YIELDS OF PIGEONPEA GROWN ON ALFISOL (MEANS FOR CVS. BDN-1 AND T-21) IN 1979 RAINY SEASON.

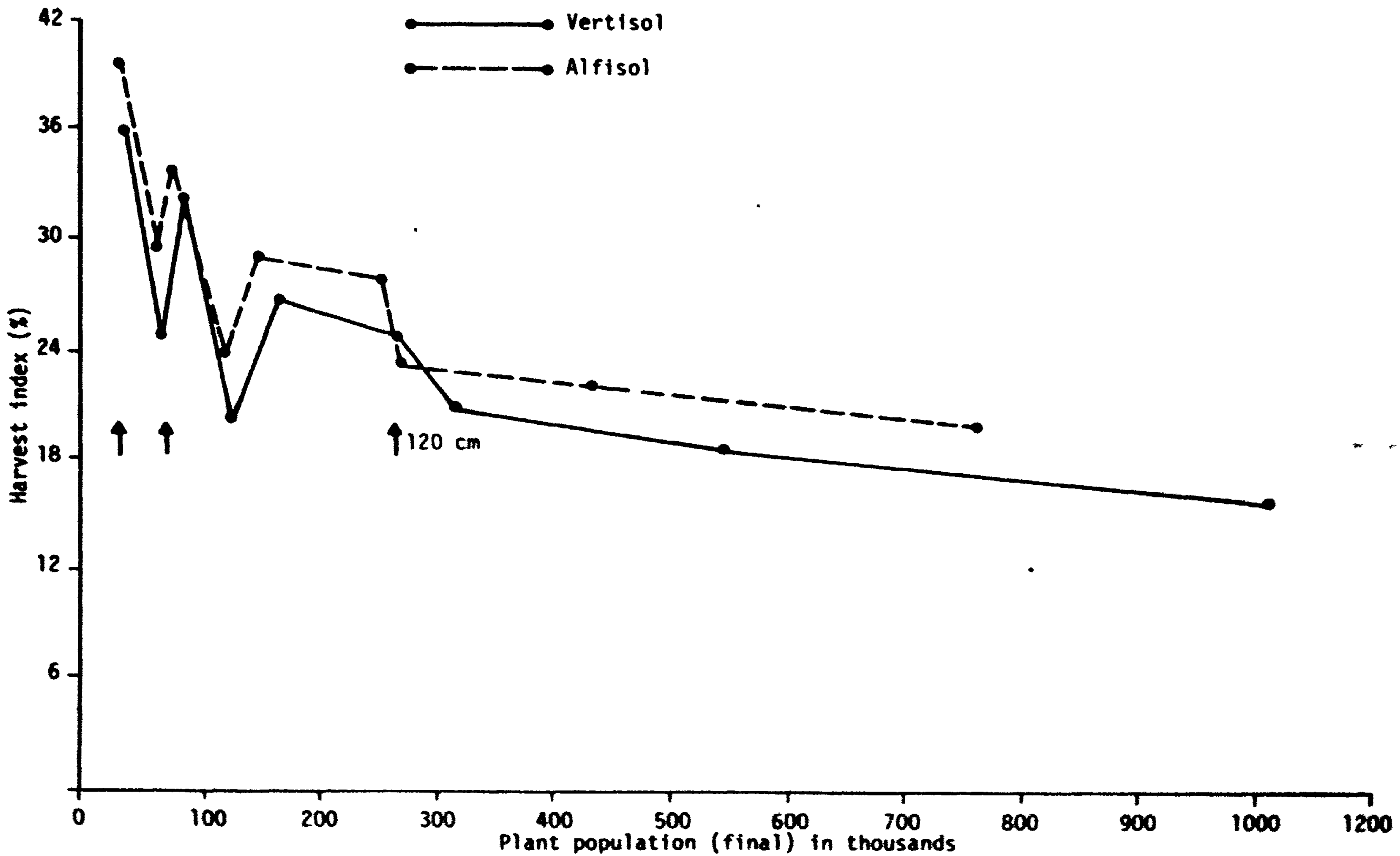

FIGURE 8. EFFECT OF PLANT POPULATION ON THE HARVEST INDEX OF PIGEONPEA GROWN ON VERTISOL (MEANS FOR CVS. BDN-1 AND C-11) AND ALFISOL (MEANS FOR CVS. BDN-1 AND T-21) IN 1979 RAINY SEASON.

Table 14. Mean yields of cultivars grown at different row-to-row and plant-to-plant spacings on an Alfisol (1979-80).

Plant-to-plant spacing (cm)	Row-to-row spacing (cm)									Plant-to-plant spacing means
	30 cm			60 cm			120 cm			
	T-21	BDN-1	Mean	T-21	BDN-1	Mean	T-21	BDN-1	Mean	
2.5	994	1188	1091	948	1289	1118	946	1359	1152	1120
10	955	1271	1113	1095	1692	1393	902	1318	1110	1205
25	1117	1239	1178	1034	1264	1149	845	1216	1030	1119
Mean	1022	1233	1127	1026	1415	1220	898	1298	1097	

Effect	L.S.D (P=0.05)
Row-to-spacing	107
Plant-to-plant spacing	NS
Row spacing X plant spacing	185
Row spacing within cultivars	151

Agronomic implications:

The results of the experiments on both soil types show that there was a broad yield plateau extending over the range of population densities from 33,000 to 666,000 plants/ha (Figs. 6 and 7). Only in cv. C-11 was there an indication of a fall in yield at the extremes of this range (Table 13).

The spacing usually recommended for medium duration cultivars such as C-11 and BDN-1 is 75 X 30 cm giving a plant populations of 44,000 plants/ha. These populations lie within the plateau region in which optimum yields are obtained on Vertisol, but may be sub-optimal on Alfisol. The data summarised in Fig. 7 show that there is no decline in yield even if populations are increased more than ten-fold above those normally recommended. The use of higher plant populations leads to considerably higher yields of stems and fallen leaves (Figs. 6 and 7) and may also give benefits in terms of grain yield on Alfisols. The fallen leaves contain approximately 1 5% nitrogen (PPR 1976/7, Table 10). So with seed rates several times higher than normal, more nitrogen is added to the soil, and a larger quantity of stems are available for use as firewood. These stems are, however smaller in diameter and may therefore be of somewhat lower value per unit weight.

Comparable results were obtained in a trial conducted in 1978/9 with cvs. BDN-1 and C-11 on both Alfisol and Vertisol. At a population density 6 times greater than normal, the grain yield remained the same, but the weights of stems and of fallen leaves increased by about 50% (Table 15).

Only a detailed economic calculations taking all these factors into account would show whether, under given conditions, the additional benefits would make the use of higher seed rates profitable. But in view of the rising costs of nitrogen fertilisers and of firewood, this possibility may merit serious consideration. In any case, at least on Alfisol, it would seem desirable to increase the recommended populations to around 100,000 plants/ha (eg. with 60 X 15 cm spacing) in order to obtain higher yields of grain.

Table 15. Yield, stem dry weight and weight of fallen leaves produced by cvs. C-11 and BDN-1 grown at normal and high populations densities on Vertisol and Alfisol (data taken from PPR 1978/9, Table 28; stem dry weights calculated by substracting seed + pod wall dry weights from total dry weight)

	Normal population (44,000 plants/ha spacing 75 X 30 cm)	High population (278,000 plants/ha spacing 30X12 cm)	LSD
Seed yield (kg/ha)			
C-11, Vertisol	1702	1652	NS
C-11, Alfisol	1314	1184	NS
BDN-1, Vertisol	1656	1873	NS
BDN-1, Alfisol	1118	1250	NS
Mean	1448	1489	
Stem weight (kg/ha)			
C-11, Vertisol	3028	4208	406
C-11, Alfisol	2701	4412	550
BDN-1, Vertisol	2832	4128	375
BDN-1, Alfisol	2361	3470	425
Mean	2731	4055	
Fallen leaf weight (kg/ha)			
C-11, Vertisol	1368	1869	220
C-11, Alfisol	871	1801	250
BDN-1, Vertisol	1228	1867	155
BDN-1, Alfisol	754	1104	202
Mean	1055	1660	

VI. SECOND HARVEST YIELDS

Pigeonpea plants go on to produce a second flush of pods if they are left standing in the field after the harvest of first flush. This characteristic perennial feature can be utilised to produce a second crop of seed during late dry season when it would not be possible to plant another crop without irrigation (PPR 1976/7; 1977/8; and 1978/9). The deep root system of pigeonpea enables it to exploit reserves of moisture at depth in the soil profile late in the season.

In the spacing experiment described above, the pods were picked from the plants of cvs. BDN-1 and C-11 at the normal time of maturity to obtain the first harvest yield. The plants were then left in the field, where they went on to produce a second flush of pods. These were then harvested to give the second harvest yield.

There was no significant effect of spacing on second harvest yields on either Vertisol or Alfisol. The most striking feature of the results was the large difference between the yields on the two soil types; the yields were much lower on Vertisol than Alfisol (Table 16).

This result is surprising. Higher yields would be expected on Vertisol than Alfisol, because more water should be available in the former during the dry period when the second flush is being produced (December - March).

However, a similar difference between soil types has been found again and again. In Table 17, data from previous pigeonpea physiology experiments are summarised. Fuller details can be found in PPR 1976/7; 1977/8, and 1978/9. For ease of comparison, only yields from non-ratooned plants are shown, i.e, plants from which pods were picked by hand at the time of the first harvest, and then left to produce a second flush In all cases the spacings, times of planting etc , on the two soil types were similar.

The fact that the yields on Vertisol are consistently less than on Alfisol indicates that some factor is inhibiting the growth of the plants on the latter. The poorer growth of plants on Vertisol during this period is clearly visible in the field. Possible explanations are:

i) a build up of nematode worms or other root parasites,

ii) toxic factors in the Vertisol, especially in the deeper regions,

iii) deficiencies of trace elements in the deeper regions of the soil,

iv) damage to the root system by cracking of the soil in the post-rainy season.

These possibilities are at present under investigation.

Table 16. Mean second harvest yields on Vertisol and Alfisol (1979-80)

Cultivar	Soil	Yield (kg/ha) ± S.E
C-11	Vertisol	41.8 ± 4.7
BDN-1	Vertisol	56.1 ± 4.6
BDN-1	Alfisol	252.6 ±13.2

Table 17. Second harvest yields of pigeonpeas on Vertisol and Alfisol in different years.

Year	Cultivar		Second harvest yield (kg/ha)	
			Alfisol	Vertisol
1976-77	No.148		882	263
	AS-71-37		1167	414
1977-78	BDN-1	-irrigation	704	334
		+irrigation	1538	286
1978-79	BDN-1	-irrigation	531	152
		+irrigation	1093	372

VII. AN ADDITIONAL EXPERIMENT ON THE EFFECT OF SOWING DENSITY ON THE GROWTH AND YIELD OF PIGEONPEAS ON VERTISOL AND ALFISOL

This experiment was originally planned as an investigation of the effect of thinning out the plant stand of pigeonpeas during the vegetative stage. Last year (PPR 1978/9, Section V.3) we found that the removal of a third or a half of the plant enabled quantities of green fodder to be harvested, with no significant loss of grain yield.

Unfortunately, the thinning treatments could not be executed because of a protracted strike by labourers. Therefore the objective of the trial was modified in order to provide additional information on the response of pigeonpeas to different sowing densities on Vertisol and Alfisol.

Methods

Two medium-duration cultivars, C-11 and BDN-1, were sowin in a flat seed bed on 30-6-79 and 13-7-79 on Vertisol and Alfisol respectively. The trial was sown in a split plot design with nine replications with cultivars in the main plots, and spacings in the sub-plots (sub-plot size: 9 X 6 M). The three spacing treatments, intended populations and final populations at the time of harvest are shown below:

Spacing (cm)	Population (plants/ha) Intended	Actual Vertisol C-11	Actual Vertisol BDN-1	Actual Alfisol C-11	Actual Alfisol BDN-1
30 X 12	277,777	275,214	277,639	225,100	225,368
50 X 20	100,000	103,828	102,853	91,591	92,943
75 X 30	44,444	45,185	46,091	40,576	42,386

The dates of planting, flowering, maturity, and harvest for the two cultivars on both Vertisol and Alfisol were as follows:

Phenology	Vertisol		Alfisol	
	C-11	BDN-1	C-11	BDN-1
Date of sowing	30-6-79	30-6-79	13-7-79	13-7-79
50% flowering	6-10-79	8-10-79	8-10-79	5-10-79
Maturity	12-12-79	12-12-79	15-12-79	20-12-79
Harvest	9-1-80	9-1-80	3-1-80	3-1-80

Results and discussion

Vertisol experiment:

There were the significant differences in yield in either cultivar at the three population densities (Table 18), demonstrating once again the ability of the plants to adjust to a wide range of spacings. As observed in the experiment reported in the previous section, the stem weights and fallen leaf weights increased considerably at the higher population densities; for example the latter increased from an average of 1.5 tons/ha at the spacing of 75 X 30 cm to 3.5 tons/ha at the spacing of 30 X 12 cm (Table 18). The yield of cv. BDN-1 was significantly higher than that of cv. C-11.

The spacing treatments had no significant effects on 100 seed weight and on seed number per pod.

Alfisol experiment:

In cv. BDN-1 the yield was significantly higher at a spacing of 50 X 20 cm than at the lower or higher population density (Table 18). In cv. C-11 the yields at 75 X 30 and 50 X 20 cm were not significantly different, but as in cv. BDN-1 the high population density was supra-optimal and gave a reduction in yield. These results are in good agreement with those of the row-to-row and plant-to-plant spacing experiment

Table 18. Effect of population density on first and second harvest yields, stem dry weight and fallen leaves in cvs. C-11 and BDN-1 on Vertisol and Alfisol.

Spacing	First harvest yield (kg/ha)		Stem dry weight (kg/ha)		Fallen leaves (kg/ha)		Second harvest yield (kg/ha)	
Vertisol								
Spacing	C-11	BDN-1	C-11	BDN-1	C-11	BDN-1	C-11	BDN-1
30 X 12	1256	1414	4368.99	4016.60	3469	3599	116	78
50 X 20	1298	1411	3333.49	3667.74	2007	2354	72	63
75 X 30	1329	1471	3556.71	3091.80	2064	895	120	96
Mean	1294	1432	3753.06	3592.05	2513	2283	103	79
L.S.D (5%)								
Cultivars	171		1244 (NS)		2140 (NS)		96 (NS)	
Spacings in a Cv.	132 (NS)		384		1067		106 (NS)	
Cvs. in a spacing	193 (NS)		1281 (NS)		2231 (NS)		124 (NS)	
Alfisol								
Spacing	C-11	BDN-1	C-11	BDN-1	C-11	BDN-1	C-11	BDN-1
30 X 12	1351	1456	3261.94	3068.70	3031	2504	261	232
50 X 20	1548	1728	3062.22	3010.75	1843	2083	295	249
75 X 30	1503	1351	2338.23	1888.99	1096	781	279	272
Mean	1467	1512	2887.46	2656.15	1990	1790	278	251
L.S.D (5%)								
Cultivars	196 (NS)		853 (NS)		880 (NS)		70 (NS)	
Spacings in a Cultivar	193		412		792		115 (NS)	
Cultivars in a spacing	240 (NS)		934 (NS)		1041 (NS)		114 (NS)	

reported above where cv. BDN-1 exhibited a significantly higher yield at a spacing of 60 X 10 cm (Table 18). This result indicates that the normally recommended spacing of 75 X 30 cm may be sub-optimal for at least some medium duration cultivars on soils of this type. In fact it would probably be better to change the standard spacing of 75 X 30 cm to a spacing of say 75 X 10 cm or 60 X 15 cm, giving a population of over 100,000 plants/ha in plantings of medium-duration cultivars under the conditions prevailing at ICRISAT Center.

As on Vertisol, the higher population densities gave a significantly greater amount of stem material and fallen leaves (Table 18). The average weights of the latter were 938, 1963 and 2767 kg/ha for the 75 X 30, 50 X 20 and 30 X 12 cm spacings respectively. As in the previous experiment, the weight of fallen leaves was somewhat lower on Alfisol than Vertisol.

The 100 seed weight and seed number per pod were not significantly affected by the spacing treatments.

Second harvest yields:

In agreement with the results of the previous experiment, the second harvest yields were extremely low on Vertisol (average 91 kg/ha) and considerably higher on Alfisol (average 265 kg/ha) as shown in Table 18.

VIII. RABI PIGEONPEA EXPERIMENTS

We conducted a series of experiments to investigate the growth, development, and yield of pigeonpeas grown as a rabi crop (PPR 1975/6; PPR 1976/7; PPR 1977/8; PPR 1978/9). Results to date indicate (i) yield levels are comparable to those of the crop grown in the normal (kharif) season, (ii) yield declines with later planting; September plantings give better yields than October, and October than November, but increased plant density will compensate for this decline in part, (iii) early cultivars mature in about 4 months and late cultivars in 5 months, the later maturing cultivars usually giving the higher yields, (iv) irrigation in the vegetative stage and again during pod filling can increase grain yield.

Last year (1978/9) in all our trials, yields were only about a third of those in 1977/8. This was probably because of the nematode population present in the field (PPR 1978/9 Table 3). Last year's experiments indicated that the cyst nematode, Heterodera cajani can become a serious pest of pigeonpeas where they are grown repeatedly in the same field. Because of the differential nematode damage, last year's results were not reliable, even though general trends were similar to previous years.

This year similar trials were planned in order to collect more information on the interaction between time of sowing and cultivars, and between time of sowing and plant density. Unfortunately, the September plantings were literally washed out by late rains, and the October plantings could not be made because of a protracted strike by labourers. The trials were sown only at the end of October and in early November.

The relatively low yield levels this year (less than 750 kg/ha in unirrigated trials) were almost certainly due to the late planting. In 1977/8, for example, the mean yields of cv. C-11 for mid-September, mid-October and mid-November sowings were 1570, 1250 and 570 kgs/ha respectively (PPR 1977/8).

Materials and methods

All of the experiments were sown in field B-10 on a deep Vertisol which was not fertilized. No post sowing irrigation was given since there was adequate moisture; irrigation was applied only in the optimum conditions study. Hand weeding was carried out as required, and the crop was sprayed to control insect pests.

1. <u>Analysis of growth, development, and yield in two hybrids and four parents grown in rabi</u>:

Two hybrids (MS-4A X C-11, and MS-3A X ICP-7035) and their four parents, MS-4A(medium); C-11(medium); MS-3A(medium); and ICP-7035(late) were used in this study. Seeds were sown at 30 X 10 cm spacing (33.3 plants m^{-2}) in four replications of randomized block design (plot size: 4.5 X 9 M).

From four replicates, plant samples were taken for destructive analysis on 40th day after sowing, and thereafter every fifteen days until maturity. Samples consisted of 5 adjacent plants. Within the plots in all four replicates, permanent quadrats were established from which fallen leaves, pods, and flowers were collected throughout the latter part of the growth of the crop. Leaf area was measured with the help of automatic leaf area meter. At harvest, yield and yield components, plant height and vegetative dry matter were measured on plots. The level of major nutrients (N,P,K) were determined in the plant material.

The phenology of two hybrids and their four parents was shown in Table 19.

Table 19. Phenology of two hybrids and their parents

Sl. No.	Cultivars and hybrids	Date of sowing	Date of 50% flowering	Date of maturity	Date of harvest
1.	MS-4A	30-10-79	22-1-80 (84)	5-3-80 (125)	23-3-80
2.	C-11	30-10-79	22-1-80 (84)	3-3-80 (123)	23-3-80
3.	MS-4AxC-11	30-10-79	20-1-80 (82)	3-3-80 (123)	23-3-80
4.	MS-3A	30-10-79	24-1-80 (86)	6-3-80 (126)	23-3-80
5.	ICP-7035	30-10-79	20-1-80 (82)	3-3-80 (123)	23-3-80
6.	MS-3AxICP-7035	30-10-79	20-1-80 (82)	5-3-80 (125)	23-3-80

Figures in parenthesis indicate number of days

2. Time of sowing X cultivar trial:

Twenty cultivars ranging in maturity from early to late were sown on 20-9-79 and 3-11-79 in four replications of a split plot design. Seeds were sown on a spacing of 50 X 8 cm (25 plants m^{-2}) with an individual plot size of 4 X 4.1 M. At harvest, yield and yield components, and plant vegetative dry matter were recorded per each plot on November sown plants.

The phenology of 20 cultivars sown in November was shown in Table 20.

3. Time of sowing X spacing trial:

Two cultivars, C-11(medium), and T-7(late) were sown at four spacings, 49 X 16.3 cm (12.5 plants m^{-2}), 34.6 X 11.5 cm (25 plants m^{-2}), 24.5 X 8.2 cm (50 plants m^{-2}) and 17.3 X 5.8 cm (100 plants m^{-2}) at each of two sowing dates (20-9-79 and 12-11-79) in four replications of a split plot design with sowing dates as whole plots, cultivars as sub-plots, and spacings as sub-sub plots (plot size: 4.0 X 4.1 M). However, the September sowings were literally washed out by heavy rains, and these plots were abandoned. The phenology of two cultivars for November sown plots was as follows:

Cultivar	Date of sowing	Date of 50% flowering	Date of maturity	Date of harvest
C-11	12-11-79	27-1-80 (76)	18-3-80 (125)	26-3-80 (133)
NP(WR)-15	12-11-79	14-2-80 (94)	3-4-80 (141)	3-4-80 (141)

4. Optimum conditions for rabi pigeonpeas:

This study was designed to find out to what extent water and nutrient shortages were limiting the growth of the rabi crop. Cv. C-11 (medium duration) was sown at 30 X 10 cm spacings (33 plants m^{-2}) in a split-plot design with irrigation treatments as main plots and foliar spray of nutrients as sub-plots (sub plot size: 3 X 3 M). The irrigation treatments were (i) no irrigation, and (ii) irrigation applied 3 times during crop growth season (on 19-1-80, 8-2-80 and 18-2-80). The following spraying treatments were applied four times during crop growth season (on 17-1-80, 6-2-80, 18-2-80 and 3-3-80):

Table 20. Phenology of 20 cultivars in the rabi varietal study

S.No.	Cultivars	Date of sowing	Date of 50% flowering	Date of maturity	Date of harvest
1.	P.A	2-11-79	14-1-80 (74)	29-2-80 (120)	5-3-80
2.	T-21	,,	14-1-80 (74)	29-2-80 (120)	5-3-80
3.	ICP-1	,,	20-1-80 (80)	3-3-80 (123)	5-3-80
4.	C-11	,,	17-1-80 (77)	3-3-80 (123)	6-3-80
5.	BDN-1	,,	16-1-80 (76)	3-3-80 (123)	6-3-80
6.	No.148	,,	18-1-80 (78)	3-3-80 (123)	6-3-80
7.	AS-71-37	,,	20-1-80 (80)	3-3-80 (123)	5-3-80
8.	JA-3	,,	20-1-80 (80)	3-3-80 (123)	5-3-80
9.	ST-1	,,	19-1-80 (79)	3-3-80 (123)	5-3-80
10.	HY-3A	,,	22-1-80 (82)	6-3-80 (120)	21-3-80
11.	6997	,,	19-1-80 (79)	3-3-80 (123)	5-3-80
12.	7035	,,	19-1-80 (79)	6-3-80 (126)	21-3-80
13.	BDN-2	,,	14-1-80 (74)	3-3-80 (123)	5-3-80
14.	HY-4	,,	12-1-80 (72)	3-3-80 (123)	5-3-80
15.	6982-6	,,	22-1-80 (82)	3-3-80 (123)	5-3-80
16.	185-8	,,	21-1-80 (81)	3-3-80 (123)	5-3-80
17.	PS-66	,,	30-1-80 (90)	6-3-80 (126)	21-3-80
18.	7065	,,	6-2-80 (97)	21-3-80 (111)	21-3-80
19.	NP(WR)-15	,,	9-2-80 (100)	21-3-80 (141)	21-3-80
20	7086	,,	6-2-80 (97)	21-3-80 (141)	21-3-80

Figures in parenthesis indicate number of days.

T_1 = Distilled water @ 750 l/ha (control)

T_2 = T_1+Urea @ 12 kg/ha

T_3 = T_1+ Urea + Single Super Phosphate @ 4 kg/ha

T_4 = T_1+ Urea + Single Super Phosphate + Micronutrients mixture 'Agromin' @ 400 g/ha

T_5 = T_1+ Micronutrients mixture 'Agromin' @ 400 g/ha

Teepol was added to the spray solutions at 0.1% concentration as a surfactant and wetting agent. The crop was harvested on 25-3-80.

Results and discussion

1. Analysis of growth, development, and yield in two hybrids and four parents

Data on the morphological characters of the plants are shown in Table 21. No features of particular interest stand out, except for the fact that cv. ICP-7035 had significantly fewer branches than the other cultivars in this season, as it did in the normal season (Table 21).

The pattern of dry matter accumulation was similar in the hybrids and their parents, as shown by the data in Fig. 9 and 10. The leaf area index

Table 21. Comparison of several morphological traits at maturity for two hybrids and four of their parents of pigeonpea (per plant) grown in rabi (1979-80)

Plant characters	C-11	MS-4A	MS-4A X C-11	7035	MS-3A	MS-3A X 7035	S.Em ±	LSD (5%)
Plant height (cms)	53.60	53.35	49.80	46.23	53.73	54.63	2.89	8.70
Stem diameter (cms)	0.40	0.41	0.38	0.46	0.40	0.40	0.017	NS
Total primary branches	6.55	5.73	6.45	2.35	4.53	5.08	0.36	1.09
Total secondary branches	0.05	0.08	0.13	0.0	0.08	0.15	0.09	NS

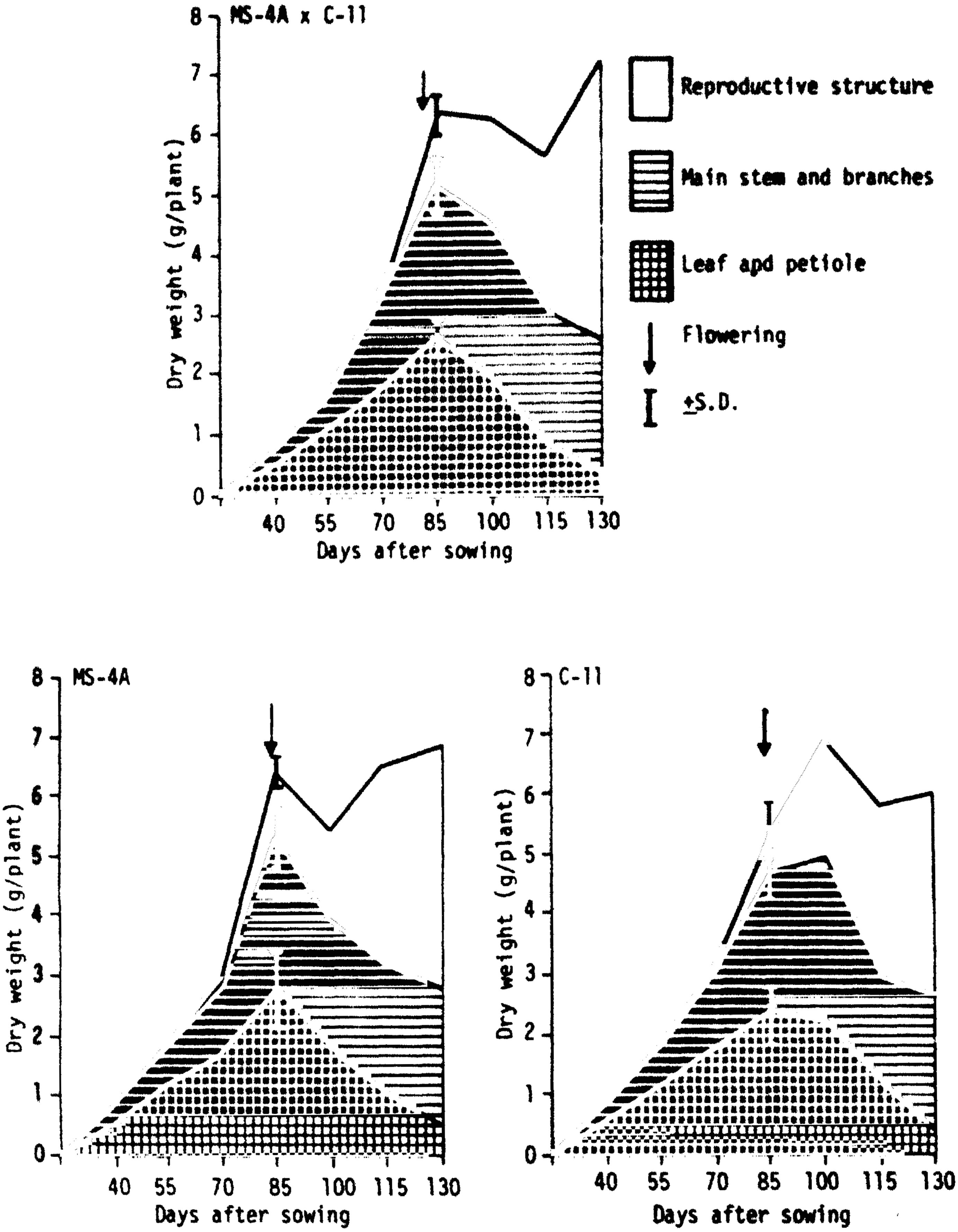

FIGURE 9. DRY MATTER DISTRIBUTION IN PIGEONPEA HYBRID AND PARENTS GROWN IN POST RAINY (RABI) SEASON 1979-80 ON VERTISOL AT ICRISAT CENTER.

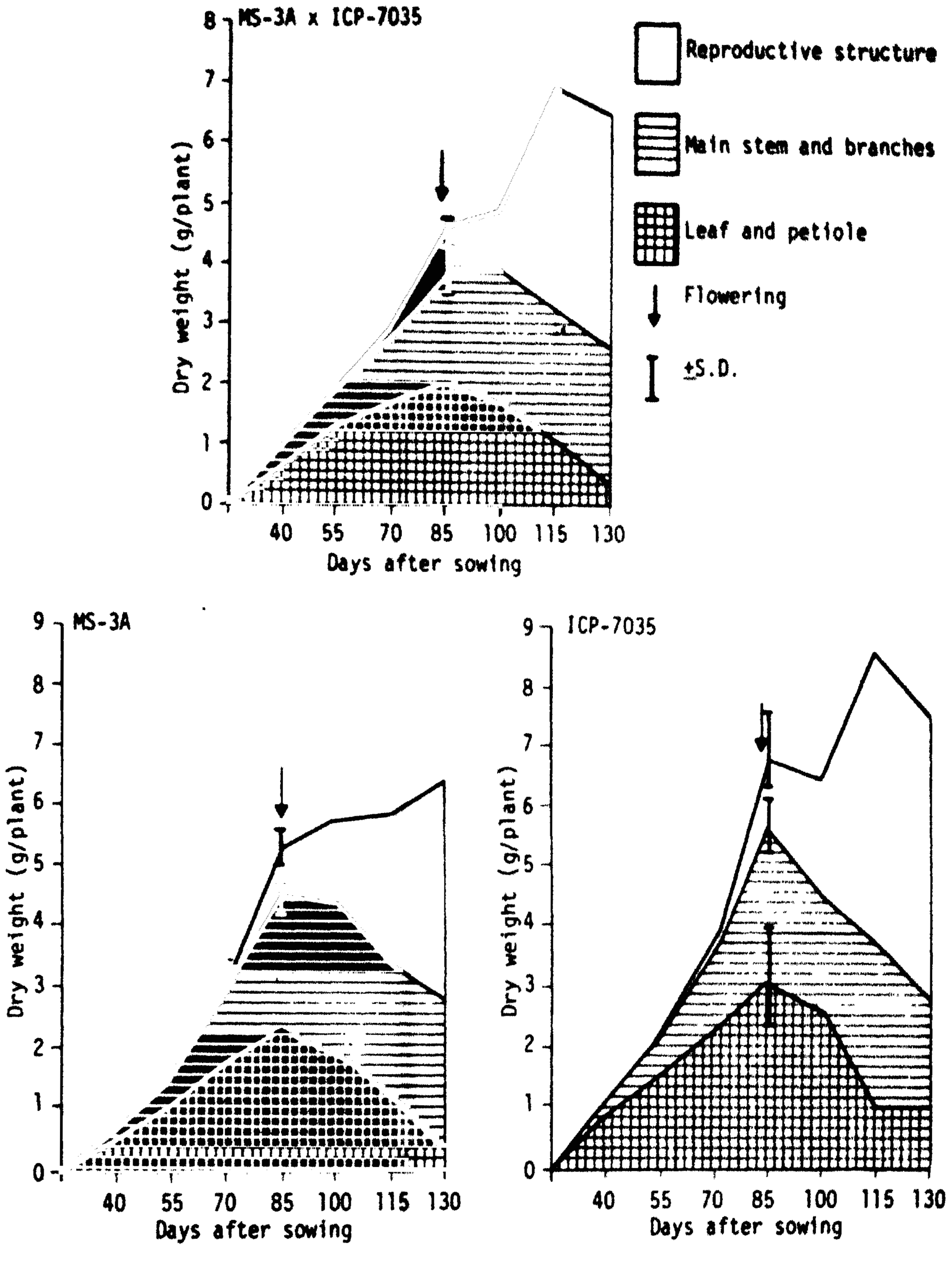

FIGURE 10. DRY MATTER DISTRIBUTION IN PIGEONPEA HYBRID AND PARENTS GROWN IN POSTRAINY (RABI) SEASON 1979-80 ON VERTISOL AT ICRISAT CENTER.

reached a maximum at the time of flowering and then declined. The maximum values were higher in cvs. C-11, and ICP-7035 (1.4) than in the male steriles and hybrids (close to 1.0); but these differences were not statistically significant (Fig. 11).

The yield and plant dry weight data from the plot harvests are shown in Tables 22 and 23. As in the normal season (Table 7), the hybrids showed no significant heterosis for yield and dry matter production. The fact that the yields of the male sterile plants were not significantly lower than those of the hybrids or pollen parents indicates that adequate pollination took place, either because they produced sufficient viable pollen themselves and/or because there was sufficient cross pollination from the non-sterile plants.

The changes in the percentages of nitrogen, phosphorus, and potassium in the different parts of the plants were also similar in the parents and the hybrids. One set of data is shown in Fig. 5. The pattern was similar to that previously observed in pigeonpeas grown in the rabi season (PPR 1977/8 Figs. 14-16).

2. Rabi pigeonpea cultivar trial

The phenological data (Table 20) for these 20 cultivars confirm the observations made in previous years that all the cultivars mature earlier when planted in the rabi season (PPR 1977/8, and 1978/9). Again, as in previous years, the harvest indices were higher and the 100 seed weights lower than in plants grown in the normal season (Table 24).

The yield levels were low owing to the late planting. But even with this short growing season, once again the early cultivars (pusa ageti, and T-21) performed significantly worse than medium and late cultivars such as ICP-1, C-11, ICP-7065 and ICP-7086 (Table 24).

3. Effects of plant population

In previous years, rabi pigeonpeas have given significantly higher yields at a population of 50 plants m^{2} than at 13 plants m^{-2} (PPR 1977/8, Table 66; PPR 1978/9, Table 46). This year a similar tendency was observed with cv. C-11, but owing to high variability between replicates this increase was not statistically significant. By contrast, the yield of T-7 showed a tendency to decline at higher population densities (Tables 25 and 26) but again this was not statistically significant.

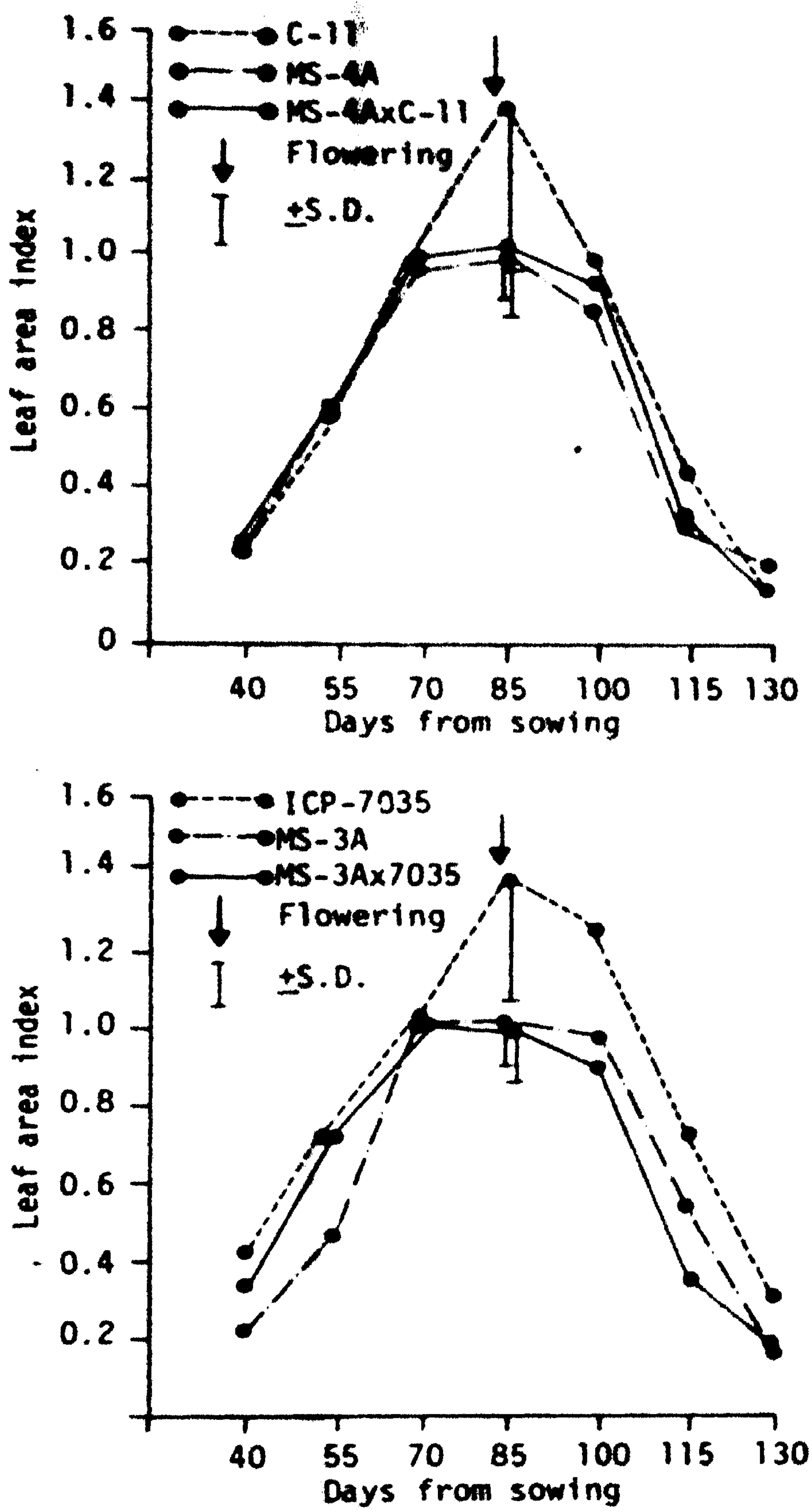

FIGURE 11. LEAF AREA INDEX OF PIGEONPEA HYBRIDS AND THEIR PARENTS GROWN IN POSTRAINY (RABI) SEASON 1979-80 ON VERTISOL AT ICRISAT CENTER.

Table 22. Yield and yield components of two hybrids and their four parent cultivars of pigeonpea grown in rabi (1979-80).

Plant characters	C-11	MS-4A	MS-4A X C-11	7035	MS-3A	MS-3A X 7035	S.Em $\pm$	LSD at 5%
Total dry matter (kg/ha)	2084.70	2014.57	1603.36	1288.86	2026.91	1872.75	199.87	NS
Total dry matter (g/plant)	7.20	6.70	5.70	7.30	7.17	6.58	0.82	NS
Yield (kg/ha)	722.10	642.66	576.21	498.97	529.27	491.30	71.69	NS
Yield (g/plant)	2.49	2.14	2.06	2.85	1.88	1.74	0.31	NS
Harvest Index (%)	34.00	31.99	35.84	38.77	25.94	27.44	2.28	6.86
100-seed wt. (g)	6.59	5.08	5.54	11.88	5.75	5.26	0.23	0.69
Seed No./pod	2.66	2.43	2.69	2.69	2.50	2.46	0.13	NS
Pod No./plant	15.50	18.88	15.45	6.53	15.00	16.23	2.67	NS

Table 23. Total fallen leaves dry weight and corrected total dry weight (kgs/ha) for two hybrids and four of their parents of pigeonpea.

Plant characters	C-11	MS-4A	MS-4A X C-11	7035	MS-3A	MS-3A X 7035	S.Em ±	LSD at 5%
Fallen leaves dry wt/ha (kgs)	260.41	288.28	240.42	109.36	197.67	295.84	51.61	NS
Corrected total dry wt/ha (kgs)	2345.12	2302.67	1843.77	1398.22	2224.58	2168.59	230.51	NS
Corrected harvest Index (%)	30.67	28.00	30.94	35.44	23.86	24.14	2.03	6.12

Table 24. Performance of 20 pigeonpea cultivars in the rabi season

Sl. No.	Cultivars	Total dry wt./ha (kgs)	Grain yield kg/ha	Harvest index (%)	100-seed weight (gms)	Pod No/ plant
		1	2	3	4	5
1.	P.A	1115.59	268.09	24.27	6.04	14.15
2.	T-21	995.36	270.04	27.43	5.62	16.33
3.	ICP-1	1744.62	573.32	33.56	5.98	24.18
4.	C-11	1393.45	467.25	33.47	6.77	11.28
5.	BDN-1	1369.27	475.07	34.60	8.48	16.15
6.	No.148	1263.44	434.26	34.38	6.61	17.68
7.	AS-71-37	1875.37	663.25	35.16	7.17	18.50
8.	JA-3	1226.05	386.36	30.76	6.48	16.28
9.	ST-1	1721.16	561.34	32.52	5.45	10.80
10.	HY-3A	979.23	357.53	36.70	11.06	13.73
11.	6997	1541.30	463.59	30.12	7.22	12.83
12.	7035	1119.99	397.36	35.79	11.89	14.75
13.	BDN-2	1328.20	491.20	37.32	6.33	20.25
14.	HY-4	1527.86	393.69	26.07	6.23	25.38
15.	6982-6	1337.00	465.54	33.58	5.77	20.55
16.	185-8	1485.58	474.34	31.78	5.93	13.47
17.	PS-66	1620.72	419.11	26.17	8.23	12.33
18.	7065	1837.73	515.64	29.23	5.74	29.25
19.	NP(WR)-15	1868.28	481.67	25.69	5.43	22.03
20.	7086	2150.92	550.34	25.37	8.57	17.08
	S.Em ±	159.75	59.42	2.34	0.55	3.00
	LSD (5%)	452.30	168.25	6.63	1.55	8.51

Contd...Table 24....

Sl. No.	Cultivars	Seed No /pod	Plant height/ plant	Fallen leaves/ha (kgs)	Corrected total dry wt/ha(kgs)	Corrected harvest index (%)
		6	7	8	9	10
1.	P.A.	1.34	43.55	114.32	1229.92	22.08
2.	T-21	1.45	43.30	104.04	1099.39	24.97
3.	ICP-1	2.22	56.25	192.06	1936.68	30.00
4.	C-11	2.10	46.40	181.59	1575.04	29.78
5.	BDN-1	1.79	44.28	218.47	1587.73	29.95
6.	No.148	2.07	49.50	145.21	1408.65	30.83
7.	AS-71-37	2.56	51.38	188.17	2063.54	32.06
8.	JA-3	1.98	47.93	108.97	1335.01	28.18
9.	ST-1	1.94	47.53	319.39	2040.55	27.41
10.	HY-3A	2.74	46.20	157.05	1136.28	32.04
11.	6997	2.59	51.48	234.17	1775.47	26.02
12.	7035	2.53	50.05	188.25	1308.24	30.10
13.	BDN-2	2.00	40.30	209.64	1537.84	32.10
14.	HY-4	1.26	54.18	169.06	1696.91	23.12
15.	6982-6	2.12	51.98	228.64	1565.64	28.81
16.	185-8	1.92	54.10	276.03	1761.61	26.93
17.	PS-66	2.12	54.88	152.00	1772.72	24.02
18.	7065	1.97	68.78	282.19	2119.92	25.62
19.	NP(WR)-15	1.88	69.93	210.28	2078.55	23.12
20.	7086	1.71	64.85	183.03	2349.46	23.36
	S.Em +	0.18	3.35	51.87	185.78	2.02
	LSD (5%)	0.51	9.49	146.87	526.02	5.71

Table 25. Effect of plant population on the grain yield of two pigeonpea cultivars grown in rabi season (1979/80).

	Grain yield/ha (kgs)		
	C-11	T-7	Mean
1. 49 x 16.3 cm(12.5 plants/m^2)	459	375	417
2. 34.6 x 11.5 cm (25 plants/m^2)	500	323	412
3. 24.5 x 8.2 cm (50 plants/m^2)	576	165	370
4. 17.3 x 5.8 cm (100 plants/m^2)	545	174	359
Mean	520	259	

L.S.D (5%)

Cultivars	202
Spacings	143 (NS)
Means within groups	203 (NS)
Means of different groups	262 (NS)
cv. main plot	46%
cv. sub-plot	35%

Table 26. Effect of plant population on dry matter production of pigeonpea cultivars grown in rabi season (1979-80).

Spacing	Total dry wt/ha (kgs)		
	C-11	T-7	Mean
1. 49 x 16.3 cm (12.5 plants/m^2)	1251	1447	1349
2. 34.6 x 11.5 cm (25 plants/m^2)	1284	1600	1442
3. 24.5 x 8.2 cm (50 plants/m^2)	1670	1163	1417
4. 17.3 x 5.8 cm (100 plants/m^2)	1809	1672	1740
Mean	1503	1470	

L.S.D (5%)

Cultivars	329 (NS)
Spacings	482 (NS)
Means within groups	682 (NS)
Means of different groups	667 (NS)

cv. main plot 20%

cv. sub-plot 31%

As in the rabi season 1977/8, the yield of the late cv. T-7 was significantly poorer than that of the medium duration cv. C-11 when planted late, in mid-November (PPR 1977/8, Table 66). This is presumably because of the more severe moisture stress to which the late cultivar was exposed towards the end of the season, and indeed stress symptoms were clearly observable in this cultivar, especially in plants at the highest population density. In previous years cv. T-7 has been found to yield just as well as cv. C-11 in September and October plantings. The interactions between cultivars, spacing, and time of planting are being investigated further.

4. Optimum conditions for rabi pigeonpeas

In order to investigate the factors that might be limiting yield in rabi pigeonpea, in this trial plants with and without irrigation were supplied with foliar sprays containing nitrogen, phosphorus and micronutrients, both separately and in combination; these sprays were applied four times, once at the end of the vegetative phase and three times during the reproductive phase. The irrigated plots received three irrigations.

As in kharif pigeonpeas in previous years (PPR 1977/8, and 1978/9) there was no significant response to spray treatments in growth or yield (Table 27 and 28) or in any other character measured. These findings indicate either that yield was not being limited by any of the nutrients supplied, or that this method of application was ineffective.

In response to irrigation, there was a large overall increase in growth and dry matter production, and the grain yields are approximately doubled (Table 27 and 28). Significant responses to irrigation of rabi pigeonpeas were also found in previous years (PPR 1977/8, Table 72; PPR 1978/9, Table 55) indicating that the availability of soil moisture is a major limiting yield, even though these deep black soils retain considerable quantities of water in the lower parts of the profile right through the rabi season CPR 1974/5, Figs. 12, 14, and 15; PPR 1974/5, Figs. 16 and 17).

Irrigation had no significant effect on seed number per pod, but led to a significant increase in 100-seed weight (Table 29). The latter result suggests that part of the reduction in 100-seed weight which occurs when pigeonpeas are grown as a rabi crop is due to water stress. The other major factor responsible for this reduction may be the cooler weather. Our previous finding that rabi pigeonpeas grown at a high density had a somewhat lower 100-seed weight than those grown at low density (PPR 1977/8, Table 71) may also be explicable in terms of increased water stress, since the former would probably have been subject to some inter-plant competition for water. A similar tendency was observed this year, although the differences were not statistically significant (Table 30).

Table 27. Effect of irrigation and foliar application of plant nutrients on total dry matter production of pigeonpea cv. C-11 grown in rabi season (1979-80).

	Total dry wt/ha (kgs)		
	+IRRI	-IRRI	Mean
1) Deionised water	2250	1460	1855
2) Urea	2271	1290	1781
3) P_2O_5	2189	1440	1814
4) Urea + P_2O_5	2103	1440	1772
5) Urea + P_2O_5 + Micronutrients	2336	1397	1866
6) Micronutrients	2252	1414	1833
Mean	2234	1407	

L.S.D (5%)	
Irrigation (groups)	266
Treatments	245 (NS)
Means within groups	345 (NS)
Means of different groups	404 (NS)
cv. main plot	16%
cv. sub-plot	13%

Irrigation also led to a significant increase in harvest index (Table 31) which at 50% was the highest we have ever observed in pigeonpeas. This is a result of considerable interest, since it indicates that under certain conditions the efficiency of partitioning of dry matter into seeds is comparable to that of chickpeas and other physiologically annual crops.

Table 28. Effect of irrigation and foliar application of plant nutrients on Grain yield/ha (kgs) of pigeonpea cv. C-11 (black soil)

	Grain yield/ha (kgs)		
	+IRRI	-IRRI	Mean
1) Deionised water	1083	619	851
2) Urea	1132	511	821
3) P_2O_5	1081	634	857
4) Urea + P_2O_5	1055	548	802
5) Urea + P_2O_5 + Micro-nutrients	1175	558	866
6) Micronutrients	1131	565	848
Mean	1110	573	

Irrigation (groups	187
Treatments	115 (NS)
Means within groups	163 (NS)
Means of different groups	233 (NS)
CV main plot	24%
CV sub-plot	13%

Table 29. Effect of irrigation harvest index, 100 seed weight and seeds per pod in cv. C-11

	+IRRI	-IRRI	LSD (5%)
Harvest Index (%)	49.7	40.7	3.2
100 seed weight (gm)	7.25	5.50	0.52
Seed No. per pod	2.81	2.77	0.15 (NS)

Table 30. Effect of plant population on 100 seed weight of two pigeonpea cultivars grown in rabi season (1979/80)

	100 seed wt. (gms)		
	C-11	T-7	Mean
1. 49 X 16.3 cm	7.06	7.90	7.48
2. 34.6 X 11.5 cm	7.13	7.31	7.22
3. 24.5 X 8.2 cm	6.08	5.98	6.03
4. 17.3 X 5.8 cm	6.21	7.38	6.79
Mean	6.62	7.14	

	LSD (5%)	F (5%)
Cultivars	1.13	NS
Spacings	1.58	NS
Means within groups	2.23	NS
Means of different groups	2.21	NS

cv. main plot 14.55 (%)

cv. sub-plot 21.79 (%)

Table 31. Effect of foliar application of plant nutrients on Harvest Index (%) of pigeonpea cv. C-11 (black soil).

	Harvest Index (%)		
	+IRRI	-IRRI	Mean
1) Deionised water	47.71	42.29	45.00
2) Urea	49.98	39.38	44.68
3) P_2O_5	49.34	43.69	46.52
4) Urea + P_2O_5	50.36	38.30	44.33
5) Urea + P_2O_5 + Micronutrients	50.43	39.91	45.17
6) Micronutrients	50.48	40.43	45.46
Mean	49.72	40.67	

	L.S.D 5%	F (5%)
Irrigation (groups)	3.15	
Treatments	3.33	NS
Means within groups	4.72	NS
Means of different groups	5.24	NS
cv. main plot	7.58%	
cv. sub-plot	7.23%	

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