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Selection of cowpea cultivars for cool-season production in the Sahel[1]

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ABSTRACT

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Cowpea (*Vigna unguiculata* (L.) Walp.) is traditionally grown during the short rainy season in the Sahelian zone of west Africa, but there are opportunities for dry-season production providing the problems of low night temperatures can be overcome. The objective of this research was to identify cultivars suitable for irrigated cropping during the cool post-rainy season. Four hundred and thirty-two lines representing breeding and local germplasm lines from Niger were tested for field emergence, flowering and podding in the coolest time of the year. A selected set of lines was evaluated for yield and other characteristics. Seedling emergence began 8 days after sowing and seedlings emerged over a 7-day period. Seventy-four percent of the local germplasm lines recorded 76–100% emergence as compared to 4% of the breeding lines. The growth of seedlings was very slow. The time to maturity was not well related to the maturity during the normal cropping season. Cooler temperatures prolonged time to maturity. All lines flowered but some did not set pods. The highest pod set was recorded in the early-maturity group. Grain yield and related attributes declined sharply when sowing was done in January as compared with the November sowing. The differences observed among selected cultivars and sowing dates were mainly due to variation in crop growth rate.

INTRODUCTION

Cowpea (*Vigna unguiculata* (L.) Walp.) is grown on small farms in the semi-arid tropics of west Africa. Production is predominantly in the short rainy season (July–September), but after the rainy season, the river Niger which traverses Mali and Niger is often full and water is available for irrigation. There is increased interest in the southern Sahelian zone of west Africa (the Sahel), particularly in Niger, in using this water to produce more food crops. There are also large areas around Lake Chad and in the Senegal river basin which are flooded, and as the floods recede farmers plant crops includ-

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ing cowpea to exploit the residual moisture. The dry season is characterized by a cool dry period starting in mid-November through February and a hot dry period thereafter until the rains in early June. Thus, depending on sowing date and duration a variety may experience sub-optimal or above optimal temperatures, or indeed both conditions. During the cool period, night temperatures usually fall well below 20°C, and may limit cowpea growth and development, while in March the temperatures may exceed the optimum of 28/22°C (Lush et al., 1980) and become limiting. However, there is little evidence of systematic investigation and exploitation of variations in cowpea varietal tolerance to low temperatures.

A range of results have been reported concerning temperature effects on cowpea. Warrag and Hall (1984a) demonstrated that average soil temperature as low as 19°C causes slow emergence and seedlings become stunted. Nielsen and Hall (1985) also reported delayed emergence when the weather was cool after sowing. This delayed emergence exposes the seeds to increased fungal and insect damage. The initiation of flowering in cowpea is determined by the prevailing combination of temperature and photoperiod (Summerfield et al., 1985). Nielsen and Hall (1985) identified high temperature during flowering as a major cause of reduced pod set and subsequent reduction in grain yield.

For indeterminate crops, Duncan et al. (1978) proposed that yield differences could be analyzed using the model:

$$Y = C * d * p$$

where Y is yield, C is the mean crop growth rate, d is the duration of reproductive growth, and p is the mean fraction of crop growth partitioned towards the reproductive sinks. This model is useful in the evaluation of the basis for yield differences because C varies with differences in 'source' characteristics while partitioning changes with 'sink' characteristics.

The objectives of this study were to: (i) assess variation for tolerance to low night temperature of seedling emergence of diverse cowpea cultivars under field conditions; (ii) determine performance of these cultivars under cool night temperatures; and (iii) determine the effect of sowing date on seed yield and other characteristics.

MATERIALS AND METHODS

Experiments were conducted in the field at the ICRISAT Sahelian Center (ISC) near Niamey, Niger (13° 15′N, 2° 18′E) during the post-rainy season (November–March of 1984–1985, 1985–1986, and 1986–1987. The experiments were conducted on a sandy soil (siliceous, isohyperthermic Psammentic Paleustaf) under irrigation.

Mean maximum and minimum daily air temperatures during the experi-

TABLE 1

Mean monthly maximum and minimum daily air temperatures (°C) from November to March (1984 to 1987)

Temperature		Nov.	Dec.	Jan.	Feb.	March
Maximum	1984/85	37±0.5	31±0.4	33±0.5	33±0.4	39±2.0
	1985/86	37±0.4	30±0.4	32±0.5	30±0.6	40±1.7
	1986/87	36±0.3	31±0.3	31±0.5	37±0.5	39±2.6
Minimum	1984/85	20±0.4	17±0.3	18±0.2	19±0.3	25±2.6
	1985/86	19±0.2	16±0.3	15±0.2	17±0.4	24±2.2
	1986/87	18±0.3	15±0.3	16±0.4	17±0.5	23±4.0

ments are shown in Table 1. These were taken from an automatic weather station situated less than 500 m from the experimental sites. No rainfall was received during the period of the experiments. In each year the field was fertilized with 18 kg P ha^{-1} prior to planting. The crop was protected from insect pests by periodic spraying of the insecticide Cymbush Super[R] Electrodyn, although insect pressure is often very low during the post-rainy season.

Germplasm screening

Experiment 1. Emergence at low temperatures

Four hundred and thirty-two lines representing breeding lines of various maturity groups (early, medium and late in the rainy season) and local germplasm lines from Niger were tested for field emergence. Seed obtained from the breeding lines in the 1984 rainy season was used. Seed for the local germplasm lines was obtained from a seed regeneration planting in 1983 of the Institut National de Recherches Agronomiques du Niger (INRAN). As much as was possible, seed lots from a common source were used to minimize variation caused by seed production in different environments. The lines were grouped into sets of 20 or more entries depending on plant type. Seeds were treated with thiram [bis(dimethylthio-carbomyl) disulphide]. One hundred seeds of each line were sown on 14 December 1984 at a uniform depth of about 2.5 cm in 2-m rows with inter-row spacing of 0.5 m. Each set was arranged in a randomized block with three replications. Irrigation was given immediately after sowing and every 4 days after. Seedling counts were taken 8, 10, 12 and 14 days after sowing (DAS) to determine percentage emergence. Soil temperature at 5 cm depth was recorded every day at 08:00 h at randomly selected sites in the field using a soil thermometer for 2 weeks after sowing. After emergence count, seedlings were thinned to ten for each line and grown for 1 month after sowing.

Experiment 2. Reproduction at low temperatures

A set of 165 breeding and 174 germplasm lines which also appeared in the emergence test were sown on 5 November 1985 in single row plots and two replications. This sowing date was to synchronize the start of the reproductive phase with the cool weather in December/January. The time from sowing to appearance of flower buds, first flowers, 50% flowering, first ripe pods and 95% maturity were recorded and used to estimate thermal time for these phenological events. Pod production on each line was assessed on a visual scale of 1 (no pods) to 5 (many pods). Based on these observations, 100 lines were selected for further evaluation.

Experiment 3. Reproduction at low temperature

The 100 lines selected were sown on 24 November 1986 in single-row plots 2-m long with a spacing of 0.6 m between rows and 0.3 m within rows. A randomized block design with three replications was used. The crop was irrigated every week. Phenology, dry matter and seed yield were determined. Flower and pod production were monitored every day on ten tagged plants to determine the reproductive efficiency of the cultivars. The number of flowers that had opened by 08:00 h each morning was counted and recorded for each of the ten selected plants. Plants used for flower counts were harvested separately and their yield components recorded.

Experiments 4 and 5. Varietal evaluation

Ten cultivars were selected for this study in 1985–1986 (Experiment 4) and 1986–1987 (Experiment 5) based on their adaptability, maturity, growth habit and stage of breeding. They included six cultivars from the breeding programs of the International Institute of Tropical Agriculture (IITA) and INRAN, and four local selections. The growth habit of the cultivars was either spreading or erect and their maturity ranged from early to late.

The cultivars were sown on 20 November 1985 and 24 November 1986 in a randomized complete block with four replications. Plots consisted of five rows 6-m long with inter- and intra-row spacing of 0.6 and 0.3 m respectively. Seeds were hand planted in hills and later thinned to 2 plants $hill^{-1}$. The three center rows were used for yield estimation.

Thermal time to flowering and maturity was calculated for the cultivars in the sowing date and variety evaluation trials according to the equation:

$$t_n = n\sum((T_{max_i} + T_{min_i})/2) - T_b$$

where t_n is the sum of cumulated degree days (°Cd) for n days, and T_{max_i} and T_{min_i} are daily maximum and minimum temperatures (°C) of day i (Rickman et al., 1983) and T_b is the base temperature. A T_b of 10°C (Grantz and Hall, 1982) was used since the T_b estimate for three of these cultivars at four dates of sowing (Experiments 6 and 7) did not differ significantly from this value.

Crop growth rates were calculated from the means as the linear rate of increase in biomass (t ha^{-1}) over the total crop growth period; as was the pod growth rate (P) for the time between 50% flowering and maturity of each genotype. The partitioning coefficient (p) was calculated as (P/C).

Experiments 6 and 7. Genotype×sowing-date responses
To examine for possible genotype by temperature interactions, a date of sowing experiment was conducted using three cultivars. The cultivars TVX3236, TN3-78 and TN5-78, were sown at four different dates (20 November, 4 and 18 December 1985, and 4 January 1986 in Experiment 6; and 18 November, 1 and 16 December 1986, and 2 January 1987 in Experiment 7). A randomized complete block with treatments in a split-plot pattern was used, with cultivars as main plots and sowing dates as sub-plots with four replications. Sub-plots were five rows, 3-m long with inter- and intra-row spacing of 0.6 and 0.3 m, respectively. Four seeds were hand planted in each hill and later thinned to two plants. Ten plants in the three center rows were randomly selected and tagged for observation of flower numbers and yield components.

RESULTS

Germplasm screening

Experiment 1
Soil temperatures at 5 cm depth from sowing until last seedling count varied between 14 and 20°C. Five nights with air temperature below 15°C were recorded during the same period. Emergence began at 8 DAS and seedlings emerged over a 7-day period. The local germplasm lines showed a greater percentage emergence than the breeding lines (Table 2). Over 70% of the local germplasm lines had 76–100% emergence as compared to only 4% of the breeding lines. Of the latter, the normally later-maturing lines were notably more able to emerge in the cool soils than the earlier-maturing lines. Growth of seedlings was slow, and by 21 DAS most lines had only one expanded trifoliate leaf. A month after sowing none of the lines had developed branches.

Experiment 2
The bulk of flowering occurred during the last two weeks of December 1985, and the first week of January 1986, when T_{max}/T_{min} were 31.3(±2.7)/14.7(±1.7)°C. Classification into maturity groups based on the rainy season time requirements did not correspond in all cases with time taken to develop

TABLE 2

Source and number of lines showing different percentage emergence in Experiment 1

Source	Emergence (%) at 14 DAS		
	<50	51–74	76–100
Breeding lines			
* Early maturing	70	44	4
Medium maturing	101	43	2
Late maturing	6	15	7
Local germplasm	8	29	103
Total	185	131	116

in the cool season since lines classified into one group could as well mature before, or after, those in other maturity groupings (Table 3).

All breeding and local germplasm lines flowered, but some did not set pods. Most of the breeding lines had a pod score rating of 2 or 3 and only a small number had a rating of 4 or 5 (Fig. 1). On the other hand most of the germplasm lines had a rating of 1 or 2 with none getting a score of 5. The majority of the lines that were rated 3 and above held their pods above the canopy. In some lines there was a mixture of well and poorly-filled pods; and some lines where the pods had few and/or shriveled seeds.

Experiment 3

During January 1987, when most of the cultivars flowered and set pods, T_{max}/T_{min} were 32.1($\pm$2.8)/14.7($\pm$1.7)°C. The characteristics measured on 100 lines selected from the 1986 trial are presented in Table 3. There were significant differences ($P < 0.05$) among lines for all characters measured.

The range of most characters was very broad, reflecting the diverse genetic background for the material. Differences were observed among lines for seedling dry weight at 21 DAS. Within maturity groups, more dry matter was produced by late-maturing cultivars than the other groups, but seed yield, as well as seed size, were slightly higher in the early-maturity group (Table 3). The lowest harvest indices were recorded in late-maturing cultivars reflecting their greater vegetative growth and their usually lower seed yield. Reproductive efficiency, as measured by the percentage of flowers that developed into pods, ranged from 27 to 95%, with the highest percentage recorded in early-maturing lines.

Simple linear correlation coefficients were obtained between nine variables. The two attributes most strongly associated with seed yield were plant dry weight and pods plant^{-1}, with correlation coefficients of 0.69 and 0.66 respectively ($P < 0.01$). Pods plant^{-1} was strongly related to the number of

TABLE 3

Ranges, means and standard errors of characters measured on 100 cowpea cultivars in the 1986/87 experiment

Character	Early maturity[a]			Medium maturity			Late maturity		
	Range	Mean	s.e.	Range	Mean	s.e.	Range	Mean	s.e.
Seedling weight (g)	2.0–5.3	3.3	0.5	0.7–5.7	3.5	0.19	1.7–6.0	3.8	0.2
Days to flowerbuds	32–58	45	0.8	42–56	49	0.75	42–67	52	1.3
Days to first flower	47–79	58	0.9	54–68	60	0.80	52–85	64	1.7
Days to 50% flower	49–82	63	0.9	59–75	67	0.90	58–88	72	1.6
Days to maturity	77–108	86	0.9	82–98	89	0.71	85–106	94	1.3
Dry matter ($g\ m^{-2}$)	103–290	192	9.0	83–393	197	15.30	80–403	239	14.9
Seed yield ($g\ m^{-2}$)	33–126	77	4.1	28–130	72	4.20	40–130	75	4.7
Harvest index	0.22–0.53	0.4	0.01	0.22–0.71	0.39	0.02	0.1–0.53	0.34	0.02
100-seed weight (g)	11.7–22.3	15.9	0.5	9.0–23.3	17	0.6	6.3–217	16.5	0.7
Total flowers	60–229	139	7.0	71–273	151	9.5	83–288	187	10.0
Total pods	34–162	76	4.4	31–149	77	4.9	39–127	86	4.4
Pod set (%)	30–95	55	2.6	27–75	53	2.4	29– 80	48	2.1

[a]Classification based on maturity in the rainy season.

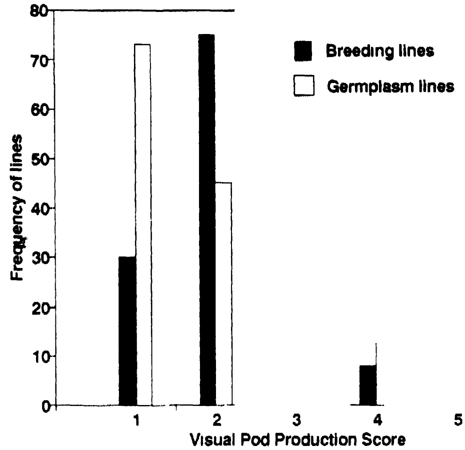

Fig. 1. Visual pod score of cowpea breeding and germplasm lines under cool-season conditions (1985/86), with a range of 1 = no pods to 5 = many pods.

pod-bearing peduncles and plant dry weight. Seedling weight was highly correlated with percent emergence ($r = 0.53, P < 0.001$).

Experiments 4 and 5

The ten cultivars differed in days to flowering and maturity (Table 4). In general, all the lines matured later than in the normal cropping season. IT84E1-108 was the earliest to flower in both years. This line matures in less than 60 DAS during the rainy season, but during the post-rainy season it required 75 days because of the lower temperatures. The other cultivars differed by a few days in reaching the various stages. IT84E1-108 needed significantly less heat units in both years than the other lines (Table 4). IT82D716 behaved like a late-maturing line, requiring the most heat units to flowering and maturity. The lines differed by up to 50% in their heat unit requirements for flowering and maturity. Year-to-year differences may reflect uncertainty about the base temperature.

The lines also differed in grain and fodder yield, and pod and flower production (Table 4). Both source and sink differences contributed to this yield response (Fig. 2). Most of these lines were similar in their reproductive sink strength, the exceptions being IT83D237, A73-1-2 and A18-1-1, and for most lines, yield differences were due to variation in C. Grain yield of lines did not fluctuate very much from year to year except for IT82D716 which had the lowest yield in 1986 when both C and partitioning were greatly reduced, and A73-1-2 which was an outlier for partitioning in 1987. The other cultivars somewhat maintained their ranking in both years. There was a tendency for better pod set in 1987 than in 1986, except in TN 27-80 which showed an 11% decline in pod set.

TABLE 4

Time to flower and maturity, accumulated degree-days, yield components, pod set, grain and fodder for ten cultivars in 1986 and 1987

Cultivar		Days to		Degree-days to		Flower		Yield (kg ha^{-1})	
		flower	maturity	flower	maturity	Number	%[a]	Grain	Fodder
1986/87	IT84E1-108	46	77	665	1116	45.4	35	800	1060
	IT82D716	73	103	1038	1660	21.0	31	70	1140
	IT83D237	56	88	789	1303	32.9	17	190	810
	B99-2-1	51	84	741	1227	26.7	52	840	1350
	A73-1-2	56	85	796	1254	14.0	59	645	1150
	A18-1-1	52	83	747	1222	28.1	45	990	950
	TN2-78	54	84	773	1236	23.2	27	525	560
	TN5-78	62	89	864	1326	31.9	33	760	1200
	TN27-80	55	88	778	1299	31.4	39	930	1160
	TN88-63	61	91	855	1313	24.7	38	580	1300
	s.e.	2.0	2.7	19	17	3.8		96	198
1987/88	IT84E1-108	48	74	565	1078	18.5	32	450	610
	IT82D716	69	99	997	1530	25.1	46	625	1260
	IT83D237	56	90	784	1359	19.7	37	350	796
	B99-2-1	50	84	685	1242	20.7	51	725	675
	A73-1-2	52	80	817	1175	13.8	55	770	700
	A18-1-1	55	88	767	1142	16.0	56	745	1050
	TN2-78	53	86	733	1279	18.8	27	515	475
	TN5-78	63	98	907	1514	19.6	48	700	825
	TN27-80	53	83	733	1225	22.6	28	790	690
	TN88-63	62	99	891	1530	21.5	79	800	1160
	s.e.	2.0	1.3	10	46	3.3		75	99

[a]Percentage of flowers resulting in pods.

Experiments 6 and 7

Both cultivar and sowing date influenced the times to first flower and maturity in 1986 and 1987, but for these three cultivars there was no interaction between these two factors (Table 5). Cultivar and sowing date both had significant ($P < 0.05$) effects on grain and fodder yield (Table 5), which declined progressively with sowing date in both years. This effect was most pronounced for grain yield in 1987. The interaction between the two factors was significant only for fodder yield in 1986. The reduction in grain yield with later sowing was associated with decreasing C ($r^2 = 0.63$) rather than due to either the duration of grain filling, or partitioning ($r^2 = 0.20$).

DISCUSSION

The slow emergence and seedling growth were consistent with the responses observed by Warrag and Hall (1984a). The differences in emergence

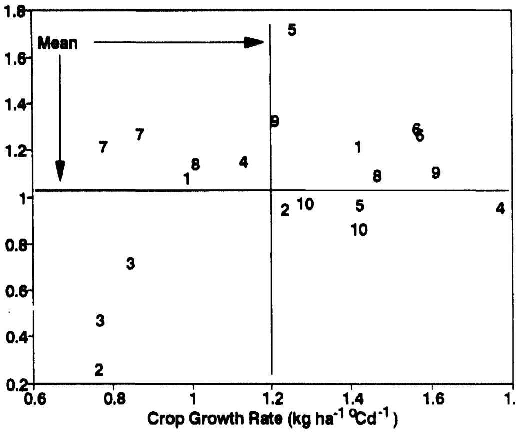

Fig. 2. Differences among ten cultivars for crop growth rate and partitioning (seed growth rate/crop growth rate) in the cool seasons of 1985/86 and 1986/1987. 1 = B99-2-1; 2 = IT83D237; 3 = A73-1-2; 4 = IT82D716; 5 = A18-1-1; 6 = TN27-80; 7 = TN88-63; 8 = TN2-78; 9 = TN5-78; 10 = IT84E1-108.

TABLE 5

The influence of cultivar and sowing date on the phenology, yield determination and productivity during the cool season of 1986/87 and 1987/88

	Cultivar or sowing date	Days to flower	Days to maturity	D_R (days)	p	C ($kg\ ha^{-1}\ day^{-1}$)	Grain yield ($kg\ ha^{-1}$)	Total yield ($kg\ ha^{-1}$)
1985/86	TN3-78	60	91	31	1.37	7.75	330	705
	TN5-78	62	93	31	0.92	11.94	340	1110
	TVX3236	65	92	27	0.83	15.98	360	1470
	s.e.	1.1	0.8	1.0	0.17	0.98	48	90
1986/87	TN3-78	59	88	29	1.33	6.65	530	585
	TN5-78	61	89	28	1.26	14.72	550	1310
	TVX3236	68	94	26	1.23	16.15	480	1530
	s.e.	0.8	0.8	1.5	0.15	0.96	48	84
1985/86	20 Nov.	66	90	24	0.89	22.44	480	2020
	4 Dec.	62	91	29	1.19	10.44	360	950
	18 Dec.	62	99	37	0.83	9.24	285	915
	4 Jan.	59	88	23	1.43	5.68	240	500
	s.e.	1.3	2.0	1.5	0.30	1.70	36	156
1986/87	18 Nov.	62	91	29	1.45	18.95	780	1830
	1 Dec.	65	97	32	1.30	13.19	520	1220
	16 Dec.	64	92	28	1.09	12.34	345	1135
	2 Jan.	55	82	24	1.34	7.68	150	630
	s.e.	1.2	1.2	2.6	0.25	1.17	32	145

D_R = Duration of reproductive growth, p = grain growth rate relative to crop growth rate, and C = crop growth rate computed over entire crop growth duration.

between the local germplasm and breeding lines are not likely to have been due to seed history because the germplasm seed was older than that of the breeding lines. This superior emergence of the germplasm lines may be because some of them have been grown by farmers under residual moisture during the cool months and are thus already adapted to the cooler temperatures of this season. This also indicates both the need to have selection pressure for these attributes, and the likelihood of making substantial genetic gains by selection for emergence under cool temperature conditions. In the second evaluation (100 lines) all cultivars flowered and set pods. This was expected since they were selected on the basis of their podding in the previous experiment. The reasonable pod set of these lines indicates that the visual rating of podding was effective as a selection criterion.

The positive correlation between seedling weight and field emergence indicated that cowpea lines which had vigorous seedlings had higher percentage emergence. However, this early vigour was weakly reflected in the final dry matter and grain yield.

In all these cool-season experiments, lines required more time to reach flowering than in the rainy season. Those lines which normally mature in 60 to 70 days behaved like medium-maturing cultivars and averaged 86 days to maturity. This effect is consistent with the reports of other workers (Lush et al., 1980; Dow el madina and Hall, 1986), and was to be expected since although the day lengths were always shorter than the critical photoperiods for the induction of flowering, the lower temperatures result in slower phenological development. In some lines, flowering occurred over an extended period while in others flowering was synchronous over a short period as indicated by time from flower bud stage to 50% flowering. There were, however, some interactions; for instance, IT84E1-108 and IT82D716 are both usually classified as extra-early (55–60 days) during the normal cropping season but in these experiments the former matured 75 DAS, while the latter took about 100 days. We have no explanation for this effect.

The large variation in flower and pod production indicated genetic differences among lines in their adaptation to low night temperature. Most of the lines with good pod setting were those with pods held on peduncles above the canopy. The reasons for this association are not clear.

The reason for the poorly filled and empty pods observed is also not clear, but the considerable differences for pod filling in these conditions suggests that screening of genotypes for reproductive capacity is necessary in the development of improved varieties for post-rainy season cropping. However, after selection of reproductive tolerance to low temperatures, most lines had good partitioning, and variations in yield therefore depended primarily on differences in source establishment, as is demonstrated in Experiments 4 to 7.

Experiments 6 and 7 showed (for a small sample of selected cultivars) that relative grain yield was not influenced by sowing date. Cowpea sown in January flowered and matured earlier than when sown in November or December, and grain and fodder were significantly reduced by later sowing. The delayed flowering in the November and December sowings may be partly due to the low night temperatures in December and January, however, this temperature effect on development was beneficial in that it resulted in higher growth rates. Clearly, canopy development was not as seriously influenced by these conditions as was phenology. The effects of low temperature on phenology are in agreement with the observations of Nielsen and Hall (1985) in cowpea, and Seddigh and Jollif (1984) in soybean. The reduced seed yield with the later sowing was associated with decreases in the number of pods; but high night temperatures during flowering and podding (Warrag and Hall, 1984b) were apparently not responsible since the minimum temperatures did not exceed 20°C until March when substantial pod set had already taken place. Given that variations in crop growth rate are strongly influenced by variations in energy interception, these results suggest that the plant populations necessary to maximize C are dependent on both sowing date and variety, and appropriate experiments are needed to generate this information.

The results of this study have implications for breeding programs in the Sahel. Presently, only one crop is possible without irrigation but it is possible to grow three generations in one year by exploiting the cool months. This should bring about faster progress in breeding, but would apply selection pressure for cool-temperature tolerance.

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