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Effects of seasonal variation in temperature and cultivar on yield and yield determination of irrigated groundnut (*Arachis hypogaea*) during the dry season in the Sahel of West Africa

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SUMMARY

In the Sudano-Sahelian zone of West Africa there is potential for groundnut (*Arachis hypogaea* L.) to be grown as a dry-season crop where irrigation is available. However, there are substantial variations in the temperatures during the post-rainy season that can be expected to influence growth and yield. An experiment at the ICRISAT Sahelian Centre was done in order to study the effect of sowing date on phenology, yield and the processes of yield determination for four groundnut cultivars under irrigation in the dry seasons of 1990/91 and 1991/92. Starting on 15 November, eight sowing dates at 2-weekly intervals were tested. Sowing date significantly affected phenology (time to emergence, flowering and maturity) with groundnut sown in November/December taking the longest time to reach these phenological stages. November and December sowings gave the highest pod yield within each year, despite the lowest crop growth rates (*B*), and yield declined progressively as sowing occurred later (50% decrease by March) despite increasing *B*. The observed responses appear to have been due to the effect of temperature differences during the pod-filling phase on partitioning. Partitioning (*p*) to pods was optimized at *c*. 30 C, with some indication of cultivar differences in partitioning response to temperature. Across all the environments, cultivars displayed substantial differences in yield stability. When sown late, yields were low and lines with high partitioning were the best. When sown early in the post-rainy season, cultivars with a high *B* value were the better choices. Plant habit differences and *B* suggest that radiation interception was a limitation to yield, particularly when the crops were sown in the cool months of the year. However, haulm yield and crop growth rates were not consistently affected by sowing date across the years, and cultivars demonstrated different degrees of stability for *B*. It is concluded that where pod has a price advantage over fodder, irrigated groundnut for the dry season should be sown in November to allow the crop to develop under the relatively cool temperatures that maximize pod yield. Further agronomic research is suggested to maximize *B* for individual cultivars for given sowing dates.

INTRODUCTION

Groundnut is usually grown in the Sudano-Sahelian zone of West Africa only as a rainfed crop. The rainy season is short, permitting only one crop per year. However, there is potential for groundnut to be grown as a dry-season crop where irrigation is possible, such as in the Niger and Senegal river basins. The dry season is characterized by a cool, dry period between November and February, when temperatures are below optimum for groundnut, followed by a rapid transition to a hot, dry period when temperatures are above optimum until June. Groundnut is sensitive to temperature, with the optimum temperature for most processes being between 27 and 30 °C (De Beer 1963). Thus in the post-rainy Sahelian environment, depending on the sowing date and its phenology, a cultivar may experience sub-optimal or supra-optimal temperatures, or indeed both conditions. Both low and high temperatures are known to affect the growth and development of groundnut

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Table 1. *Rainfall (mm), relative humidity (%), pan evaporation (mm day^{-1}), and radiation (MJ m^{-2} d^{-1}) at the ICRISAT Sahelian Centre in Niger, West Africa during experiments in 1990/91 and 1991/92*

Month	Rainfall	Mean relative humidity	Pan evaporation	Radiation
		1990/91		
Nov	0	15	8·1	17·8
Dec	0	14	7·1	15·9
Jan	0	12	7·9	17·7
Feb	0	9	8·4	18·6
Mar	8	14	10·5	18·1
Apr	14	23	9·3	19·5
May	94	49	6·5	19·2
Jun	121	52	6·3	21·6
		1991/92		
Nov	0	11	7·1	20·8
Dec	0	15	6·6	20·4
Jan	0	18	7·4	18·6
Feb	0	10	9·7	23·1
Mar	0	11	10·2	22·0
Apr	12	18	9·8	22·9
May	44	38	8·4	22·2
Jun	85	47	8·0	23·1

(Bell *et al.* 1991*a*, *b*). Groundnut cultivars with different temperature adaptation are known (Williams *et al.* 1978). However, little is known about adaptation to temperature variations across phases of development.

The yield of any crop can be defined by a simple physiological model (Duncan *et al.* 1978):

$$Y = B \times D_r \times p \qquad (1)$$

where Y = pod yield; B = mean crop growth; D_r = duration of the reproductive phase; and p = a partitioning coefficient of B to reproductive structures. Variations in B are dominated by light interception (Duncan *et al.* 1978; Monteith 1990), while variations in D_r are determined largely by temperature (Ong 1986), and p by cultivar and cultivar × environment interactions (Duncan *et al.* 1978; Williams 1992).

In the present study the yields, individual parameters of the growth model (Eqn 1), and the phenology of four contrasting groundnut cultivars when sown on eight dates under irrigation were examined in order to detect the most appropriate period for sowing groundnut in the dry season. Such information will be useful in guiding further research, in developing management strategies that can enable the use of the long dry season for groundnut production, and will provide useful information for model development.

MATERIALS AND METHODS

The experiment was conducted during two seasons (1990/91 and 1991/92) at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Sahelian Centre Research Farm, 45 km south of Niamey, Niger (13° N, 2° E). The soil is sandy (Psammentic paleostalf) with a very low water-

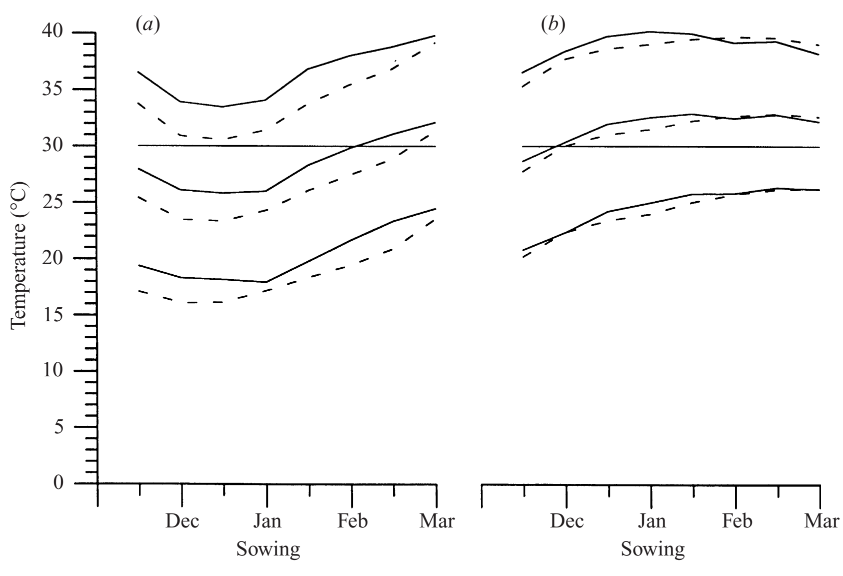

Fig. 1. Mean, minimum and maximum temperatures relative to the optimum for groundnut growth during (*a*) vegetative and (*b*) reproductive phases of growth as determined by sowing date at Sadore, Niger; 1990/91 (——) and 1991/92 (– – –).

Table 2. *Effect of sowing date on days to* 50 % *flowering* (*calendar and physiological days*) *of four groundnut cultivars sown at Sadore*, *Niger in 1990/91 and 1991/1992. Physiological days are the estimated thermal time equivalent of 24 h at optimum temperature* (*30 °C*)

	Cultivar (calendar days)					
Sowing date	47–16	55–437	28–206	ICGS11	Means for dates	Physiological days
1990/91						
15 Nov	41	37	43	39	40	36·2
30 Nov	51	40	48	44	45	36·3
15 Dec	52	43	54	43	48	36·9
30 Dec	*	43	47	44	45	34·6
15 Jan	41	38	44	39	40	37·0
30 Jan	34	33	39	33	35	35·3
15 Feb	37	32	37	31	34	37·6
2 Mar	34	30	34	31	32	37·0
Mean (cultivars)	43	37	43	37		

S.E. between dates 0·8 (20 D.F.); between cultivars 0·6 (72 D.F) ; cultivars within dates 1·6 (72 D.F)

* Data excluded due to poor emergence.

	Cultivar (calendar days)					
Sowing date	47–16	55–437	28–206	ICGS11	Means for dates	Physiological days
1991/92						
15 Nov	46	39	49	39	43	32·5
30 Nov	55	49	56	50	53	33·4
15 Dec	56	53	59	54	55	32·7
30 Dec	51	46	52	45	48	31·1
15 Jan	46	38	47	41	43	32·3
30 Jan	43	37	47	37	41	34·2
15 Feb	38	33	41	34	37	35·2
2 Mar	36	32	38	32	35	38·7
Mean (cultivars)	43	44	44	45		

S.E. between dates 0·74 (21 D.F.); between cultivars 0·45 (72 D.F.); cultivars within dates 1·32 (72 D.F.)

holding capacity and organic matter content. Four released West African groundnut cultivars were used in the experiment: 55–437 (Spanish bunch), ICGS 11 (Spanish-type), 47–16 (Virginia runner) and 28–206 (Virginia bunch). The first two cultivars are of short duration, maturing in < 110 days while the last two are of long duration, maturing in > 120 days in the normal season. Each cultivar was sown on eight dates separated by 14-day intervals from 15 November 1990 to 2 March 1991 and from 15 November 1991 to 2 March 1992.

Treatments were replicated four times in a randomized block in a split-plot arrangement with sowing dates as main plots, and cultivars as subplots. The subplot was four rows 0.5 m apart and 6 m long. Thirty-six kg ha^{-1} P_2O_5 as single superphosphate and 16 kg ha^{-1} N were applied before sowing and 400 kg ha^{-1} of gypsum was applied at pod formation. Seeds were sown by hand and the crop was irrigated weekly with 40 mm of water using overhead sprinkler irrigation in 1990/91 and a linear movement system (Valley Irrigation Inc) in the 1991/92 season.

The plots were observed for flowering and the date when 50 % of the plants had flowered noted. Maturity was decided according to the percentage of pods that had internal staining (Williams & Drexler 1981). At maturity, the two centre rows of the plot were harvested by hand and dried at 80 °C for at least 36 h before pod and haulm dry weights were determined.

The *B* and *p* values were estimated using the non-destructive methods described by Williams & Saxena (1991) and Williams (1992) after the dry matter was adjusted to account for the high energy of kernels. To do this, pod dry matter was multiplied by 1·65 (Duncan *et al.* 1978); a value reflecting the ratio of carbon production costs of shoot and pod dry matter. Crop growth rates were calculated over the entire crop duration, while the pod growth rates (*PGR*) were calculated from the time between 50 % flowering and harvest. The *p* was calculated as PGR/B (Duncan *et al.* 1978).

The phenological data for days to 50 % flowering from different sowing dates were used to estimate the base temperature (T_b) for the cultivars used in this experiment (13 °C), there being small differences between cultivars. The optimum temperature (T_o) and the maximum temperature (T_m) were not calculated. Thermal times for the phenological phases were computed using the air temperature measured at the meteorological station located *c.* 500 m from the experimental field and cardinal temperatures of T_b = 13°, T_o = 30° and T_m = 40 °C according to Mohamed *et al.* (1988). Thermal time expressed as physiological days was based on 24 h at T_o constituting a physiological day.

The data were subjected to standard analysis of variance, and then the stability analysis concepts of Finlay & Wilkinson (1963) were used to compare the parameters of the yield determination model for each cultivar across 'environments' as defined by combinations of years and sowing dates.

RESULTS

Data for cv. 47–16 sown on 30 December 1990 were excluded from the analysis because only 10% emergence was achieved.

Environment

The weather (excluding temperature) experienced during the experiments in the two years is presented in Table 1. However, since sowing dates differed so greatly, consideration of the conditions prevailing during various phases of growth is more appropriate. The mean temperatures for the period between sowing and 50% flowering (vegetative phase) and between flowering and maturity (reproductive phase) were calculated for each sowing date treatment (Fig. 1). The years were similar for the temperatures over the reproductive phase, but 1991/92 was appreciably cooler than 1990/91 during the vegetative phase. Late sowing increased the mean temperatures during both phases by *c*. 5 °C relative to the early sowing dates.

Phenology

All the cultivars took progressively less time to flower (Table 2) and to complete reproductive processes (Table 3) as sowing was delayed from December to March. Time to flowering decreased by nearly 2 weeks in the 1990/91 season as sowing was delayed from December to March while in the 1991/92 season the decrease was close to 3 weeks. Cultivars 47–16 and 28–206 took longest to flower.

Reproductive duration ranged from 72 to 96 days in the 1990/91 season, and from 87 to 111 in the 1991/92 season (Table 3). In 1990/91, groundnut sown in March averaged 104 days to maturity while sowing in the cool months resulted in 137 days to maturity. On the other hand, in 1991/92 maturity was

Table 3. *Effect of sowing date on reproductive period (calendar and physiological days) of four groundnut cultivars sown at Sadore, Niger in 1990/91 and 1991/1992*

Date	Cultivar (calendar days)				Means for dates	Physiological days
	47–16	55–437	28–206	ICGS11		
1990/91						
15 Nov	108	81	107	88	96	89·2
30 Nov	92	81	102	91	91	95·0
15 Dec	99	73	98	81	88	97·9
30 Dec	*	65	75	78	73	84·6
15 Jan	86	64	83	75	77	90·7
30 Jan	89	82	85	83	85	98·6
15 Feb	80	60	79	61	70	83·4
2 Mar	75	69	74	72	72	83·5
Mean (cultivars)	88	73	88	78		

S.E. between dates 2·09 (20 D.F.); between cultivars 1·24 (72 D.F.); cultivars within dates 3·69 (72 D.F.)
* Data excluded due to poor emergence.

Date	47–16	55–437	28–206	ICGS11	Means for dates	Physiological days
1991/92						
15 Nov	118	104	115	107	111	95·3
30 Nov	109	89	108	102	102	101·4
15 Dec	99	97	79	85	90	96·1
30 Dec	95	80	95	88	89	97·9
15 Jan	98	79	97	84	90	102·6
30 Jan	93	74	89	78	84	98·4
15 Feb	92	81	89	87	87	102·8
2 March	83	76	81	85	81	94·9
Mean (cultivars)	98	83	96	90		

S.E. between dates 1·09 (21 D.F.); between cultivars 0·65 (72 D.F.); cultivars within dates 1·94 (72 D.F.).

Table 4. *Effect of sowing date on pod yield* ($t\ ha^{-1}$) *of four groundnut cultivars at Sadore, Niger in 1990/91 and 1991/1992*

Date	Cultivar 47–16	55–437	28–206	ICGS11	Means for dates
1990/91					
15 Nov	3·6	1·8	1·6	2·5	2·4
30 Nov	3·3	2·5	3·0	3·6	3·1
15 Dec	3·0	2·1	2·9	3·1	2·8
30 Dec	*	2·5	2·0	2·6	2·4
15 Jan	3·1	1·9	2·2	2·7	2·4
30 Jan	2·4	2·7	1·6	2·7	2·3
15 Feb	1·3	1·6	0·6	1·5	1·2
2 Mar	1·4	1·7	0·8	1·8	1·4
Mean (cultivars)	2·4	2·1	1·8	2·6	

S.E. between dates 0·288 (20 D.F.); between cultivars 0·123 (72 D.F.) ; cultivars within dates 0·418 (72 D. F.).
* Data excluded due to poor emergence.

Date	Cultivar 47–16	55–437	28–206	ICGS11	Means for dates
1991/92					
15 Nov	1·6	1·6	1·3	2·1	1·6
30 Nov	2·5	1·5	1·0	1·3	1·6
15 Dec	1·6	1·5	0·8	1·2	1·3
30 Dec	1·2	1·0	0·6	1·1	1·0
15 Jan	1·1	1·1	0·6	1·0	0·9
30 Jan	0·7	1·0	0·5	0·9	0·8
15 Feb	0·7	1·1	0·4	0·8	0·8
2 Mar	0·4	0·8	0·2	0·8	0·6
Mean (cultivars)	1·2	1·2	0·7	1·2	

S.E. between dates 0·135 (21 D.F.); between cultivars 0·088 (72 D.F.); cultivars within dates 0·255 (72 D.F.).

achieved in an average 116 days for the March sowing and 150 days for the November/December sowing.

The variation in the rate of development from sowing to flowering ($1/f$), and from 50% flowering to maturity ($1/D_r$) was examined by linear regression against the mean air temperature (Bell *et al.* 1991 *a*, *b*). Mean daily temperature was positively and linearly related to the rate of phenological development from sowing to flowering, and from flowering to maturity in all cultivars. The coefficient of determination values for individual cultivars ranged from 0·74 to 0·97 (n = 8) for the rate to flowering in 1990/91 and from 0·80 to 0·93 in 1991/92. The relationships between mean daily temperature and the rate of development of pods ($100/D_r$) were less clear and the coefficient of determination values ranged from 0·22 to 0·60 in 1990/91 and from 0·38 to 0·77 in 1991/92. This poorer relationship may be due to the assumptions made about when pod-filling starts, but most of the variation was accounted for by temperature because thermal time estimates for these phases did not differ greatly across sowing dates (Tables 2 and 3). However, given that irrigation was at regular intervals, the longer calendar time taken by the early sowing incurred a greater water and management cost than did later sowing.

Pod yield, seed mass and numbers and shelling percentage.

Both sowing date and cultivars had a significant ($P < 0·01$) effect on pod yield. Pod yield of all cultivars declined by > 50% in both years from early sowing (mid-November/early December) to later sowing (mid-February/early March) (Table 4). The interaction of cultivar with sowing date was not statistically significant within either year. However, the stability analysis approach combining years and sowing dates shows that the cultivar 55–437 was best when yields were lowest (i.e. late sown and exposed to highest temperature) and lowest when the environment promoted yield (Fig. 2). Haulm yields were less affected by sowing date and only cultivar effects were significant (Table 5). One-hundred-seed mass (size) was highest in the November/December sowing and lowest in the February/March sowing, while threshing percentage only varied slightly across sowing dates (data not shown).

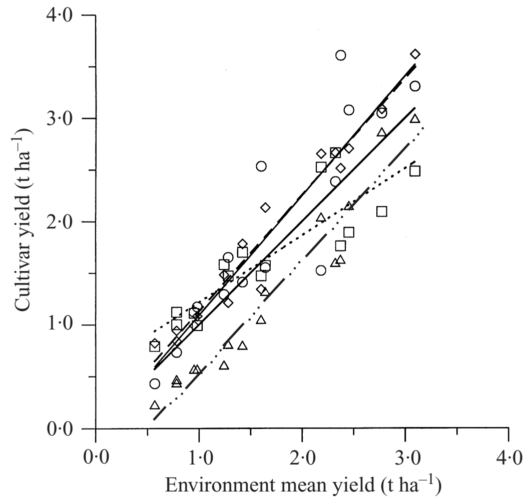

Fig. 2. Pod yield stability across eight dates of sowing at Sadore, Niger; in 1990/91 and 1991/92 for four groundnut cultivars. The lines represent the regression of individual cultivars on the mean of all cultivars in each combination of year and sowing date.

47–16:	○——	$y = 1{\cdot}159x - 0{\cdot}069$	$R^2 = 0{\cdot}82$
55–437:	□ ……	$y = 0{\cdot}649x + 0{\cdot}566$	$R^2 = 0{\cdot}78$
28–206:	△ …_…	$y = 1{\cdot}078x - 0{\cdot}521$	$R^2 = 0{\cdot}94$
ICGS11:	◇ – – –	$y = 1{\cdot}127x + 0{\cdot}003$	$R^2 = 0{\cdot}96$

Unit slope——

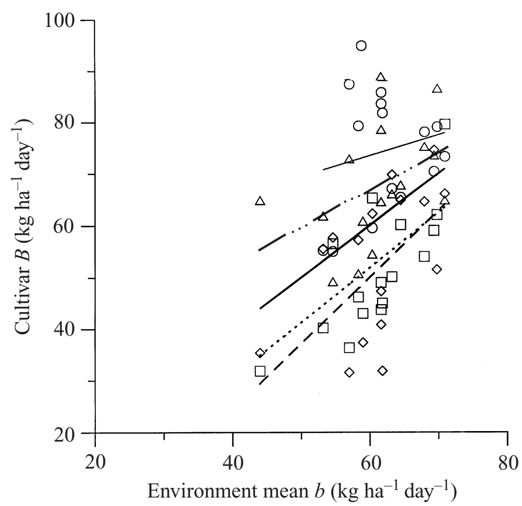

Fig. 3. Stability of crop growth rate across eight dates of sowing at Sadore, Niger; 1990/91 and 1991/92 for four groundnut cultivars. The lines represent the regression of individual cultivars on the mean of all cultivars phase in each combination of year and sowing date.

47–16:	○——	$y = 0{\cdot}406x + 49{\cdot}1$	$R^2 = 0{\cdot}03$
55–437:	□ ……	$y = 1{\cdot}286x - 27{\cdot}2$	$R^2 = 0{\cdot}59$
28–206:	△ …_…	$y = 0{\cdot}707x + 24{\cdot}3$	$R^2 = 0{\cdot}19$
ICGS11:	◇ – – –	$y = 1{\cdot}063x - 11{\cdot}9$	$R^2 = 0{\cdot}29$

Unit slope——

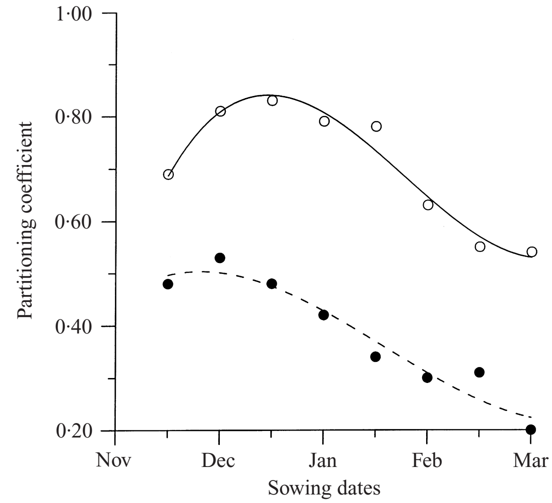

Fig. 4. Average response of partitioning by four groundnut cultivars across eight dates of sowing at Sadore, Niger; 1990/91 (○——) and 1991/92 (●– – –).

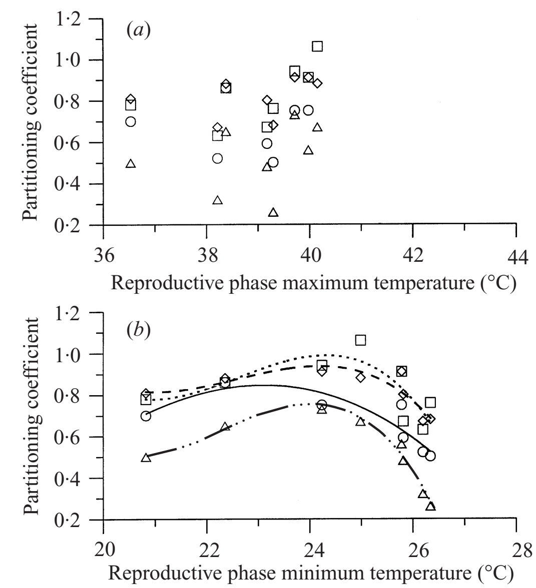

Fig. 5. Relationship between partitioning and (a) maximum and (b) minimum temperature during the pod-filling phase of four groundnut cultivars across eight dates of sowing at Sadore, Niger; 1990/91 and 1991/92. The lines represent the regression of individual cultivars on the mean of all cultivars over this phase in each combination of year and sowing date.

47–16:	○——	$y = -4{\cdot}85 + 0{\cdot}0886x + 0{\cdot}0243x^2 - 0{\cdot}0007x^3$	$R^2 = 0{\cdot}80$
55–437:	□ ……	$y = 126{\cdot}8 - 16{\cdot}885x + 0{\cdot}750x^2 - 0{\cdot}0111x^3$	$R^2 = 0{\cdot}60$
28–206:	△ …_…	$y = 126{\cdot}6 - 17{\cdot}206x + 0{\cdot}778x^2 - 0{\cdot}0116x^3$	$R^2 = 0{\cdot}97$
ICGS11:	◇ – – –	$y = 89{\cdot}41 - 11{\cdot}869x + 0{\cdot}528x^2 - 0{\cdot}0078x^3$	$R^2 = 0{\cdot}78$

Table 5. *Effect of sowing date on haulm yield* ($t\ ha^{-1}$) *of four groundnut cultivars sown at Sadore, Niger in 1990/91 and 1991/1992*

Date	Cultivar 47–16	55–437	28–206	ICGS11	Means for dates
1990/91					
15 Nov	5·75	2·25	4·75	3·00	3·94
30 Nov	4·25	3·23	6·00	4·00	4·38
15 Dec	5·25	2·75	5·25	3·50	4·19
30 Dec	*	2·25	5·00	3·25	3·50
15 Jan	4·75	2·25	6·25	2·75	4·00
30 Jan	5·25	4·50	5·50	3·25	4·62
15 Feb	4·50	2·75	4·75	2·75	3·67
2 Mar	4·00	3·75	4·50	3·50	3·94
Mean (cultivars)	4·96	2·96	5·3	3·25	
S.E. between dates 0·353 (20 D.F.); between cultivars 0·232 (72 D.F.); cultivars within dates 0·669 (72 D.F.).					
* Data excluded due to poor emergence.					
1991/92					
15 Nov	3·94	1·91	4·82	2·78	3·36
30 Nov	6·16	1·59	6·18	1·56	3·87
15 Dec	7·24	1·92	4·89	1·93	4·00
30 Dec	4·92	1·40	5·17	1·75	3·31
15 Jan	6·15	2·01	6·29	2·07	4·13
30 Jan	6·35	2·30	4·84	2·34	3·96
15 Feb	5·72	2·01	6·54	1·49	3·94
2 Mar	5·28	3·29	6·02	2·84	4·36
Mean (cultivars)	5·72	2·05	5·59	2·09	
S.E. between dates 0·693 (21 D.F.); between cultivars 0·294 (72 D.F.); cultivars within dates 1·000 (72 D.F.).					

Crop growth rates and partitioning

Crop growth rates varied across sowing dates and years (Table 6), with a different pattern of B for each year. In 1990/91, B was maximized by sowing in January and February, while in 1991/92, B increased progressively with later sowing. These differences between years in response of B across sowing dates are partly explained by a weak relationship of B with the temperature conditions prevailing in the vegetative phase (coefficient of determination = 0·27).

Crop growth rate responses also differed with cultivar, with B of cultivar 55–437 and ICGS 11 being less than that of 28–206 and 47–16 (Fig. 3). The stability analysis for B found that the B of cultivar 47–16 was not related to the 'environmental mean', and that the intercept for 55–437 and ICGS 11 was below the unit slope, but the results were not statistically significant.

Partitioning varied strongly across the years and sowing dates (Table 7), however the response to sowing date within years was consistent (Fig. 4). Cultivars 55–437 and ICGS 11 had the highest partitioning coefficients at all dates of sowing in the two seasons. The relationship between temperature during the pod-filling phase and partitioning in 1990/91 is shown in Fig. 5. Maximum temperatures during the reproductive phase were not well related to partitioning but there was a good relationship between minimum temperatures and partitioning, with evidence of cultivar differences in partitioning response to mean minimum temperatures. The minimum temperatures of *c*. 24 °C were optimum for partitioning.

DISCUSSION

The results showed that groundnuts may be grown successfully in the post-rainy season in the Sahel. The analysis of the yield-determination model parameters points to areas that require further research to maximize productivity in this cropping opportunity. The instability of production across years, however, remains a cause for concern, and further research should be undertaken at a wider range of sites.

Table 6. *Effect of sowing date on crop growth rate (kg ha*$^{-1}$ *day*$^{-1}$*) of four groundnut cultivars sown at Sadore, Niger in 1990/91 and 1991/1992*

Date	Cultivar 47–16	55–437	28–206	ICGS11	Means for dates
1990/91					
15 Nov	79·2	46·2	50·7	57·2	58·4
30 Nov	70·3	59·0	73·5	74·5	69·3
15 Dec	67·0	50·1	66·0	69·7	63·3
30 Dec	*	60·1	67·7	64·8	64·1
15 Jan	78·0	54·0	75·2	64·5	67·9
30 Jan	73·2	79·5	64·8	66·0	70·9
15 Feb	55·0	56·5	49·2	57·7	54·6
2 Mar	59·5	65·2	54·5	62·2	60·4
Mean (cultivars)	68·4	58·9	62·7	64·6	

S.E. between date 5·58 (20 D.F.); between cultivars 3·02 (72 D.F.); cultivars within dates 9·26 (72 D.F.).
* Data excluded due to poor emergence.

Date	47–16	55–437	28–206	ICGS11	Means for dates
1991/92					
15 Nov	55·2	40·2	61·8	55·5	53·2
30 Nov	87·3	36·3	72·8	31·5	56·9
15 Dec	94·8	43·0	60·8	37·3	58·9
30 Dec	69·0	31·8	64·8	35·3	50·2
15 Jan	83·5	43·7	78·5	40·8	61·6
30 Jan	85·7	49·0	64·5	47·3	61·6
15 Feb	81·7	45·0	88·8	31·8	61·8
2 Mar	79·0	62·0	86·5	51·5	69·7
Mean (cultivars)	79·5	43·9	72·3	41·3	

S.E. between dates 10·09 (21 D.F.); between cultivars 3·99 (72 D.F.); cultivars within dates 14·04 (72 D.F.).

Partitioning was clearly the major cause of yield differences between the two years. However, the source of this difference was not obvious from the data and other observations. Comparison of the weather data for the two years shows that 1991/92 (with the poorest partitioning) had a cooler vegetative phase, but it is not clear why the results for a given temperature should be so different. Deficiency in calcium supply for pod nutrition can cause variations in partitioning (Hartmond *et al.* 1994) but, since shelling percentage was similar for the two years, this source of variation can be discounted. Variations in the irrigation can also be discounted as a source of variation in partitioning between years, since the primary productivity was very similar for the two experiments (63·6 *v.* 59·2 kg^{-1} ha^{-1} day^{-1}).

Sowing date responses were consistent across years, yields of all cultivars being highest in the November/December sowings, these being at least 50% more than those obtained from March sowings. These differences were mainly due to the progressive decrease in partitioning with sowings later than early December (Fig. 4). This decline in partitioning is closely associated with the mean minimum temperature during the reproductive phase of crop growth. The importance of the minimum temperature rather than the maximum temperature may be explained by the fact that flowering occurs during the night and early morning and pollen viability is sensitive to temperatures > 33 °C (De Beer 1963). These results differ from those of Williams *et al.* (1975) and Young *et al.* (1979), who found that pod yield was optimized at temperatures below the general optimum. Stability analysis of partitioning showed no cultivar interactions.

In both years, *B* increased with later sowing from November to February or March but the response patterns from cultivars were different. Some of the differences in response may be attributed to the temperatures during the vegetative phase but there was still considerable instability in the response of *B* to sowing date for unidentified reasons. However, resource capture models, and the fact that the later maturing lines (47–16 and 28–206) had the higher *B*, suggest that these differences are likely to be associated with canopy development; therefore, research to find the sources of this instability seem particularly appropriate.

Cultivars differed in their yield, with both *p* differences and *B* variations being significant sources

Table 7. *Effect of sowing date on partitioning of growth to reproductive structures by four groundnut cultivars sown at Sadore, Niger in 1990/91 and 1991/1992*

Date	Cultivar				Means for dates
	47–16	55–437	28–206	ICGS11	
1990/91					
15 Nov	0·70	0·78	0·50	0·81	0·69
30 Nov	0·86	0·86	0·65	0·88	0·81
15 Dec	0·75	0·94	0·73	0·91	0·83
30 Dec	*	1·06	0·67	0·88	0·87
15 Jan	0·75	0·91	0·56	0·91	0·78
30 Jan	0·59	0·67	0·48	0·80	0·63
15 Feb	0·50	0·76	0·26	0·68	0·55
2 Mar	0·52	0·63	0·32	0·67	0·54
Mean (cultivars)	0·65	0·82	0·52	0·82	

S.E. between dates 0·038 (20 D.F.); between cultivars 0·022 (72 D.F.); cultivars within dates 0·065 (72 D.F.).

* Data excluded due to poor emergence.

Date	47–16	55–437	28–206	ICGS11	Means for dates
1991/92					
15 Nov	0·38	0·63	0·31	0·60	0·48
30 Nov	0·44	0·77	0·23	0·69	0·53
15 Dec	0·29	0·73	0·25	0·63	0·48
30 Dec	0·30	0·65	0·15	0·56	0·42
15 Jan	0·22	0·53	0·12	0·48	0·34
30 Jan	0·15	0·47	0·16	0·42	0·30
15 Feb	0·16	0·51	0·09	0·49	0·31
2 Mar	0·10	0·33	0·05	0·30	0·20
Mean (cultivars)	0·26	0·58	0·17	0·52	

S.E. between dates 0·037 (21 D.F.); between cultivars 0·018 (72 D.F.); cultivars within dates 0·058 (72 D.F.).

of pod yield variation. The cultivars 55–437 and ICGS11 compensated for lower growth rates by having high partitioning. The different responses of cultivars across sowing date and year for B (Fig. 3), suggests that canopy development of the shorter duration Spanish types was more sensitive to low temperatures than was that of the Virginia cultivars. Two factors could have acted to create this effect, without differential sensitivity of cultivars to low temperature. First, the shorter time before flowering would have limited the canopy development before flowering commenced and, second, the differences in partitioning would have resulted in different amounts of canopy growth during the reproductive phase. Thus, although sowing in the cooler months maximized p, it also limited canopy development (particularly so for the high partitioning and early flowering cultivars) so that counteracting yield determining forces came into play. The lack of sensitivity displayed by cv. 47–16 (runner habit) which could have higher B when other cultivars had low B, supports the idea that spacing and population changes are needed to ensure complete light capture.

The lack of a strong interaction between sowing date and cultivar for yield within years may be taken to suggest that choice of cultivar can be made without considering when production will occur. The lack of interaction occurred because the variations in B compensated for the changes in p. Since the evidence suggests that B can be manipulated by appropriate management to maximize energy interception by the crop, this would suggest that yields will be maximized by the correct combination of cultivar and management. Late sowing should use those cultivars with p least affected by temperature (these results and Greenberg *et al.* 1992).

In this study, average daily temperature during kernel development (Fig. 1) was generally above the ranges reported as optimum (Williams *et al.* 1975; Young *et al.* 1979) and seed size generally declined with later sowings, which experienced higher temperatures (data not shown). Although there would be wide system implications to the idea, the use of short season cultivars in the normal cropping season could allow sowings earlier than tested in these experiments. This could be more desirable still, since canopy and fruit initiation would occur before temperatures became limiting to canopy and fruit development and seed sizes would be maximized.

In the Sudano-Sahelian zone with the existing rainy season-based crop system, it would be desirable to sow irrigated groundnuts in November. This would provide sufficient time for the crop to be harvested before the onset of the high temperatures in March, thus avoiding extreme atmospheric aridity and very warm temperatures. As such it is probable, given the responses observed in the present study, that a phenologically adapted dry-season cultivar would flower in *c*. 35 days and mature *c*. 136 days from sowing.

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