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\daptation of Sorghum/Maize and Sorghum/Pearl Millet Intercrop Systems to the Toposequence Land Types in the North Sudanian Zone of the West African Savanna

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ABSTRACT

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Cereal/cereal intercrop systems are commonly used by farmers in the higher-rainfall areas of the South Sudanian and Guinean savanna zones of West Africa. Towards the North Sudanian zone these systems become less common, because of a shorter rainy season with a more abrupt start and end. However, previous work on the responses of maize (*Zea mays*), sorghum (*Sorghum bicolor*), and pearl millet (*Pennisetum americanum*) crops to the different toposequence land types indicated that crop mixtures of sorghum/millet for uplands and sorghum/maize for lowlands would be less prone to drought stress and waterlogging risks than would the respective sole crops.

The present studies showed consistent intercropping advantages of at least 25% for sorghum/maize systems when both crops are sown at the same time. The relative advantages from this system were greatest for the uplands.

Intercropping advantages were generally less for the sorghum/millet systems, and it proved essential to delay the millet sowing to prevent serious competition to the sorghum. Sorghum/millet intercropping provides a risk-reducing alternative to sole cropping, because sorghum plants lost during the common early droughts can be replaced by an early-maturing millet sown in July. However, because of the unpredictability of the early-season rainfall, sorghum/millet systems will be difficult to standardize; both the sowing date and the plant densities of the component crops may require adjustments each year in response to the starting date of the rains and the extent to which the sorghum has survived the early-season droughts.

INTRODUCTION

Throughout the tropics, farmers tend to grow their crops in intercrop systems rather than as sole crops. Very complex systems involving five or more

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annual and perennial crops are often grown in the humid tropics (Okigbo, 1981), while in the semiarid tropics two or three crops, usually annuals, are combined in a single field (Kassam, 1976; Kabore et al., 1983). Given the socioeconomic conditions of most farmers, and the large variability in soils and rainfall, intercropping is increasingly recognized as a viable strategy for spreading the risks of crop failure, and the labour demands for the critical operations of sowing, early weeding and harvesting (Norman, 1974). By contrast, agricultural research and rural development projects have, in the past, frequently promoted sole-crop systems, because of easier technical recommendations and technology transfer, and greater suitability for mechanization.

Two major local intercropping systems can be recognized for the West African savanna: the cereal/cowpea systems where cowpeas are added to a full stand of the cereal base crop as discussed in a previous article (Stoop, 1986); and the cereal/cereal systems where one of the component crops partially replaces the other.

Cereal/cereal intercropping is a very common local practice in the West African savanna (Steiner, 1982). It is particularly widespread in the wetter Guinea and South Sudanian zones where the cropping season is about 150–200 days long (Kowal and Kassam, 1978). Early non-photosensitive crops are mixed with late photosensitive crops; the former are harvested up to 3 months prior to the latter, which rely on residual soil moisture to mature. Examples of such systems, as shown in Table 1, include the early millet/late sorghum systems of northern Nigeria (Norman, 1974) or the maize/late millet system of southern Mali (DRSPR, 1984). The yield gains of 35–80% due to intercropping as compared to sole cropping have generally been attributed to the 'competition gap' between the early and late-maturing crop components of the system (Baker and Yusuf, 1976; Willey, 1979) and the fact that floral initiation in the second crop often occurs only after the harvest of the first (Andrews, 1972). Moreover, the competition gap can be widened and the early competition to the first crop reduced by postponing the sowing of the second crop for several weeks (Baker, 1974).

Cereal/cereal intercrop systems are less common in the North Sudanian zone, where the growing season varies from 90 to 130 days. The complementarity between millet, sorghum and maize in their adaptation to various toposequence landtypes (Van Staveren and Stoop, 1985; Stoop, 1986) indicates, however, that with adapted crop cultivars which are able to exploit the competition gap, cereal/cereal intercropping has a potential to both increase as well as stabilize total cereal production in this zone. The present study investigated various sorghum/maize and sorghum/millet intercrop systems including their adaptation to different landtypes.

MATERIALS AND METHODS

Four complementary experiments on cereal/cereal intercropping were conducted from 1981 to 1983, at the Kamboinsé experiment station (12°28′N;

TABLE 1

Some major local cereal/cereal intercropping systems for various areas in the West African savanna (early cultivars are non-photosensitive, late cultivars photosensitive)

Rainfall zone (mm/year)	Area	Start of rains	End of rains	Soil type	Cropping systems	Sowing period	Harvest period
900-1000	Northern Ghana	April/May	October	Coarse sandy (upland)	Early millet	May	July
					+ late millet	May/June	November
				Coarse sandy (lowland)	Early millet[1]	May	July
					+ late sorghum	May/June	November
900-1000	Southern Burkina Faso	April/May	October	Sandy loam	Red sorghum	May/June	August/September
					+ late millet	June	November
900-1000	Southern Mali	April/May	October/ November	Sandy loam	Maize	May/June	August/September
					+ late millet	June	November/December
600- 700	Central Burkina Faso	June	September	Sandy loam (upland)	Late sorghum	June	October
					+ late millet	July	October

[1]A similar system occurs in northen Nigeria (Norman, 1974).

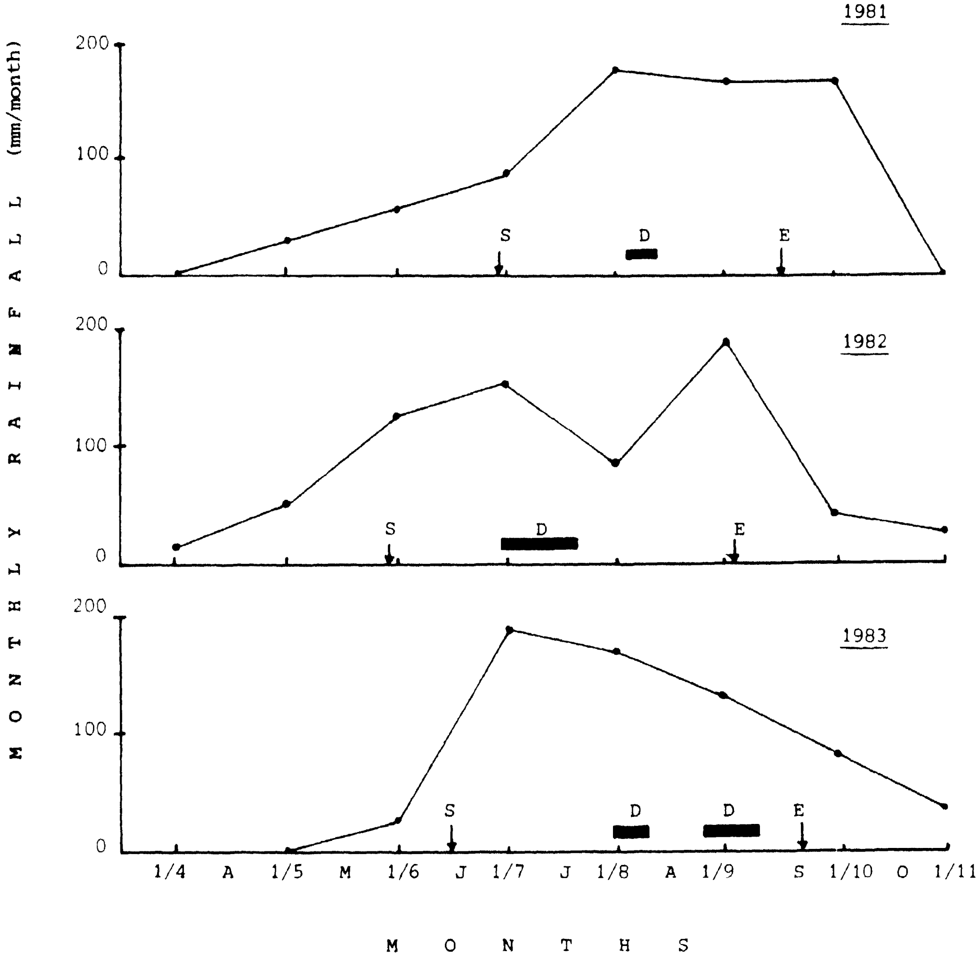

Fig. 1. Monthly rainfall distribution at the Kamboinsé experiment station; annual variations in start (S) and end (E) of the rains is indicated, as is the occurrence of major droughts (D) over the period 1981–1983.

1°33′W), about 10 km north of Ouagadougou in central Burkina Faso (formerly Upper Volta). Detailed information about the semiarid climate and the soil conditions as related to the topography has been reported elsewhere (Van Staveren and Stoop, 1985; Stoop, 1987). Though total annual rainfall varied little between years (700 mm in 1981, 717 mm in 1982, and 663 mm in 1983) its distribution within years differed greatly. Consequently droughts (Fig. 1), defined here as periods during which plants showed distinct wilting symptoms, influenced the crops to different degrees in each of the three seasons.

With reference to earlier results (ICRISAT, 1978, 1979), the present trials investigated the stability of sorghum/maize systems across different toposequence land types in response to varying plant densities of the component crops, and to different sorghum genotypes. The sorghum/millet trials investi-

ABLE 2

·eneral plant characteristics for sorghum, millet, and maize cultivars used in the various experiments

ꞌrops and cultivars	Plant type	Experiment	Year	Plant characteristics	
				Days to 50% flowering	Plant height (cm)
ꞌorghum					
Kamboinsé local (late cultivar)	Photosensitive, tillering	2	1981	(72-75)	370-405
		1 and 3	1982	(80-82)	375-410
940S	Slightly photosensitive, tillering	3	1982	75-80	200-230
Framida	Slightly photosensitive, non-tillering	3	1982	76-78	220-250
Kamboinsé local (early cultivar)	Photosensitive, tillering	4	1983	(80-84)	370-390
E35-1	Slightly photosensitive, non-tillering	4	1983	78-84	210-225
Millet					
Kamboinsé local	Photosensitive, tillering	1	1982	(79-81)	320-365
Ex Bornu	Non-photosensitive, tillering	4	1983	49-53	230-265
Maize					
J. Flint de Saria	Non-photosensitive, non-tillering	2	1981	49-51	240-260
		1 and 3	1982	48-51	200-230

The 'days to 50% flowering' for photosensitive cultivars occur between brackets, since these numbers may vary annually in response to the actual sowing date.

gated whether the millet competition effect on sorghum could be lessened by reducing millet density, or by delaying the millet sowing. The trials included sole-crop plantings, for comparisons.

Experiment 1: Comparison between sorghum/maize and sorghum/millet intercrop systems

In this study, local cultivars (Table 2) were employed because of their ability to perform under very diverse soil and rainfall conditions. The sole crops were sown at two densities: 40 000 and 80 000 plants/ha for sorghum and maize: 20 000 and 40 000 plants/ha for millet. The intercrops were sown as alternate rows, with sorghum at a constant 40 000 plants/ha, maize at either 20 000 or 40 000 plants/ha, and millet at either 10 000 or 20 000 plants/ha. The resulting ten treatments (six sole crops and four intercrops) were laid out in a randomized complete-block design and replicated eight times. The trial was planted on 18 June, 1982; maize was harvested on 16 September, sorghum on 14 October, and millet on 19 October.

Experiment 2: Sorghum/maize intercropping on different toposequence land types as influenced by plant densities of the two component crops

Local photosensitive sorghum and non-photosensitive maize (Table 2) were: 1) sown as sole crops at 40 000 and 80 000 plants/ha; and 2) intercropped by sowing in alternate rows. With each sole crop being sown at two densities there were four intercrop combinations, with total populations 40 000, 60 000 and 80 000 plants/ha. The four sole-crop and four intercrop treatments were randomized and replicated at six different positions along the toposequence, representing two major land types: relatively dry mid-slopes, and relatively wet lower slopes. The performance of each crop in the intercrop situation was statistically analyzed as a single replication of a $2 \times 2 \times 6$ factorial (2 densities of the base crop $\times 2$ densities of the intercrop $\times 6$ toposequence positions). In addition to the major effects, various 'factor $\times$ land type' interactions were also estimated and tested for their statistical significance by using the pooled higher-order interactions as the residual error term in the F-tests.

All the crops were sown on 26 June, 1981; maize was harvested on 21 September, and the Kamboinsé local sorghum on 17 October.

Experiment 3: Sorghum/maize intercropping on different toposequence land types as influenced by sorghum genotypes

Three sorghum cultivars (Kamboinsé local; 940S; and Framida) and maize (Table 2) were each sown at two densities (40 000 and 80 000 plants/ha) and, further, were combined in six intercrop treatments (each sorghum cultivar at 40 000 plants/ha plus maize, at 20 000 or 40 000 plants/ha); sorghum and maize were sown in alternate rows. The eight sole-crop and six intercrop treatments were randomized and replicated at eight different toposequence positions, with two positions in each of the four major land types: uplands, upper, mid, and lower slopes. The performance of each crop in the intercrop situation was statistically analyzed as a single replication of a $3 \times 2 \times 8$ factorial trial (3 sorghum cultivars $\times 2$ densities of the intercrop $\times 8$ toposequence positions), using the same method as described for Experiment 2.

All crops were sown on 18 June, 1982: maize was harvested on 16 September; 940S and Framida on 8 October; and the Kamboinsé local sorghum on 14 October.

Experiment 4: Sorghum/millet intercropping for upper and mid-slope fields

This trial combined two sorghum cultivars, Kamboinsé early local and E35-1, with an early millet, Ex Bornu (Table 2). Both crops were sown at the same density: sole crops at 60 000 plants/ha; and intercrops at 30 000 plants/ha of each, in alternate rows. Sorghum was sown on 20 June 1983, while the millet sowing was delayed by either 9 or 21 days. The third factor in this trial was nitrogen fertilizer side-dressing to the millet, at rates of 0 and 16 kg N/ha 4 weeks after planting. The sorghum rows received the regular urea side-dressing of 65 kg urea/ha 5 weeks after planting.

The trial was laid out as a randomized complete-block design to which the six sole-crop plots were added at random, with three replications; the result was analyzed as a 2^3 factorial (2 sorghum cultivars × 2 levels of N × 2 sowing dates). The millet treatments were harvested on 13 and 21 September, sorghum E35-1 on 8 October, and the local sorghum on 15 October. The different land types in experiments 2 and 3 were separated by drains, bunds, and/or cultivated strips. Following ploughing and ridging, the crops were sown on the side of ridges 75 cm apart. For all experiments, the plot size was 4.5 × 5 m.

All trials received a uniform application of the 100 kg 14:23:15 NPK/ha after ploughing and before ridging, followed by a side-dressing of 65 kg urea/ha which was incorporated into the soil at the time of the second weeding (usually 4–5 weeks after sowing).

Comparisons between treatments were primarily made on the basis of their grain yields and, to a lesser extent, the 'Land Equivalent Ratio' (LER), which estimates the relative land area under sole crops that would be required to produce the yields achieved in intercropping (Willey, 1979).

All experiments suffered from field heterogeneity and occasional droughts, which caused considerable variability of both intercrop and sole-crop yield data as reflected by relatively high coefficients of variation; consequently, the values which were subsequently calculated from those yield data, in particular the LER values, should be interpreted with some reservation.

RESULTS

Comparison between sorghum/maize and sorghum/millet intercrop systems (Experiment 1)

The results summarized in Table 3 show several clear trends in spite of the large field variability. First of all, the sole-crop data clearly demonstrate the differences in yield potential between maize, sorghum, and millet when grown under the same soil conditions and agronomic management. Secondly, the yields of sorghum grown as sole crop or in combination with a maize or millet intercrop differed significantly. Whereas sorghum yields were hardly affected by the presence of a low-density maize intercrop, they were halved when intercropped with millet. The impact of increased plant density was generally insignificant for the sole crops as well as for the intercrop systems. An exception was the high-density sorghum/maize intercrop treatment where 50% replacement of sorghum by maize caused a significant decrease in sorghum yield not compensated for by a matching or greater increase in maize yield (Table 3). Probably the serious July drought (Fig. 1) just prior to maize flowering was responsible for the lack of yield response to increased maize density.

The favorable performance of the sorghum/maize system (LER > 1) can be explained by the competition gap between the maize, which flowered on 7 August and the sorghum, which flowered on 7 September 1982; however, this situation did not apply when the same sorghum cultivar was intercropped with early millets (ICRISAT, 1979) or with the local millet that flowers at about the same time as the local sorghum. Moreover, the data in Table 3 also demonstrate that lowering the millet intercrop density from 20 000 to 10 000 plants/ha did not significantly improve the yields of the sorghum intercrop, thereby confirming the highly competitive nature of millet as a function of its profuse tillering ability and its extensive root system. Experiment 4 was therefore designed to investigate whether this competition can be reduced by using an early-maturing millet cultivar and delaying millet sowing.

Adaptation of sorghum/maize intercrop systems to land types

In view of the consistent superiority of sorghum/maize systems, investigations were carried out to determine:

whether the system could be intensified by increasing the plant densities and expanded to the drier land types of the toposequence (Experiment 2); and

whether the system could be modified for the drier land types by introducing sorghum cultivars that mature earlier than the local sorghum, or by reducing the maize intercrop plant density (Experiment 3).

Effects of sorghum and maize plant densities (Experiment 2)

During the 1981 season rainfall was low, stopping early in the 2nd week of September, though its distribution till then had been very even. As a result, the yields of sole sorghum were below those of sole maize (Fig. 2) because of a lack of residual soil moisture; the sorghum crop flowered on 8 September, whereas the maize had already flowered, on 15 August. In previous seasons, however, sorghum frequently outyielded maize on both drought-stressed mid-slopes and waterlogged lowlands (Van Staveren and Stoop, 1985).

When the sole-crop density was raised from 40 000 to 80 000 plants/ha, there was no significant impact on sorghum yields, while maize yields declined by

TABLE 3

Comparisons of sorghum/maize and sorghum/millet intercrop systems with their respective sole crops (local cultivars) during the 1982 season

	Plant densities (no./ha)			Grain yields (kg/ha)			LER			
	Sorghum	Maize	Millet	Sorghum	Maize	Millet	Sorghum	Maize	Millet	Total
Cropping systems										
Sole crop	40 000	40 000	20 000	1860	2930	1030	-	-	-	-
	80 000	80 000	40 000	1730	3090	930	-	-	-	-
Sorghum/maize	40 000	20 000	-	1740	1400	-	0.94	0.48	-	1.42
	40 000	40 000	-	1400	1500	-	0.75	0.49	-	1.24
Sorghum/millet	40 000	-	10 000	950	-	390	0.51	-	0.38	0.89
	40 000	-	20 000	910	-	640	0.49	-	0.63	1.12
s.e. (±)				130	245	91				
C.V. (%)				25.8	31.0	34.3				

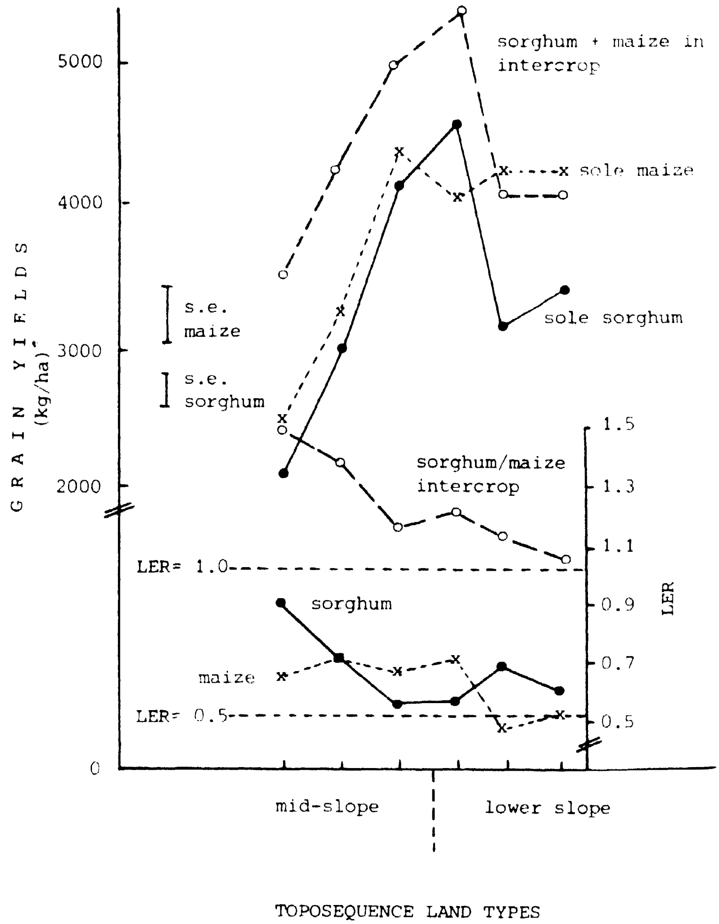

Fig. 2. Sorghum, maize, and total intercrop grain yields, and corresponding land equivalent ratios (LER) by toposequence land types, for three mid-slope positions on moderately deep loamy soils and three lower-slope/lowland positions on moderately deep to deep silty loam soils.

22% (Table 4). In contrast, the same total density *increase* in the sorghum/maize intercrop system (by raising each component crop from 20 000 to 40 000 plants/ha) did result in highly significant ($P<0.01$) and marginally significant ($P<0.1$) yield increases of 32% for sorghum and 28% for maize (Table 4); under these circumstances the yield loss of the competing intercrops was always of lesser scope, being 11% for maize (non-significant) and 18% for sorghum (significant at $P<0.05$). The combined result therefore indicated that higher total plant densities can be used for the intercrop than for the sole crop situation.

Toposequence observations indicated that, whereas sole-crop responses of maize and sorghum to land types were large, the responses were non-significant for the intercrops (Table 4). In addition, the LER values for each of the component crops were consistently above 0.5, while the total LER value increased towards the drier mid-slope land types (Fig. 2).

TABLE 4

Maize and sorghum intercrop and sole crop yields, and corresponding LER values, as affected by different plant densities and toposequence land types (Experiment 2; 1981)

	Maize grain yield (kg/ha)				Sorghum grain yield (kg/ha)		
	Intercrop	Sole crop	LER maize		Intercrop	Sole crop	LER sorghum
Maize density (50% of sole crop)	N.S	*		Sorghum density (50% of sole crop)	**	N.S.	
20 000 per ha	2000	4270	0.47	20 000 per ha	1830	3460	0.53
40 000 per ha	2560	3340	0.77	40 000 per ha	2420	3360	0.72
s.e. (±)	189	346		s.e. (±)	94	89	
Cropping system (=density competing sorghum crop)	N.S.			Cropping system (=density competing maize crop)	*		
20 000 per ha	2410	—		20 000 per ha	2340	—	
40 000 per ha	2150	—		40 000 per ha	1910	—	
s.e. (±)	189			s.e. (±)	94		
Land type	N.S.	*		Land type	N.S.	**	
Mid-slope	2230	3390	0.66	Mid-slope	2020	3100	0.65
Lower slope	2330	4210	0.55	Lower slope	2230	3760	0.59
s.e. (±)	328	424		s.e. (±)	162		
Interactions	N.S.	—		Interactions	N.S.	—	
C.V. (%)	28.8	22.3		C.V. (%)	15.3	9.0	

N.S.: non-significant.
*: significant F test at 1% level.
**: significant F test at 5% level.

Consequently, the gains in total grain yield increased from 10% on the lowest to 50% on the highest land type as a result of intercropping, thereby contributing to a much greater yield stability across land types for the intercrop than for the respective sole-crop systems.

Effects of sorghum cultivars (Experiment 3)

The response of sole sorghum to different land types was again highly significant as were the differences between cultivars (Fig. 3A). Though still highly significant, these responses were reduced when the various sorghum cultivars were intercropped with maize; notably the large yield difference between 940S and Framida under sole cropping disappeared in the intercrop situation (Fig. 3A and B). Moreover, the Kamboinsé local and Framida intercrops grown at 40 000 plants/ha yielded only slightly less than their sole crops as shown by a sorghum LER of 0.86; for 940S this value was 0.70 (Table 5). Thus, in the

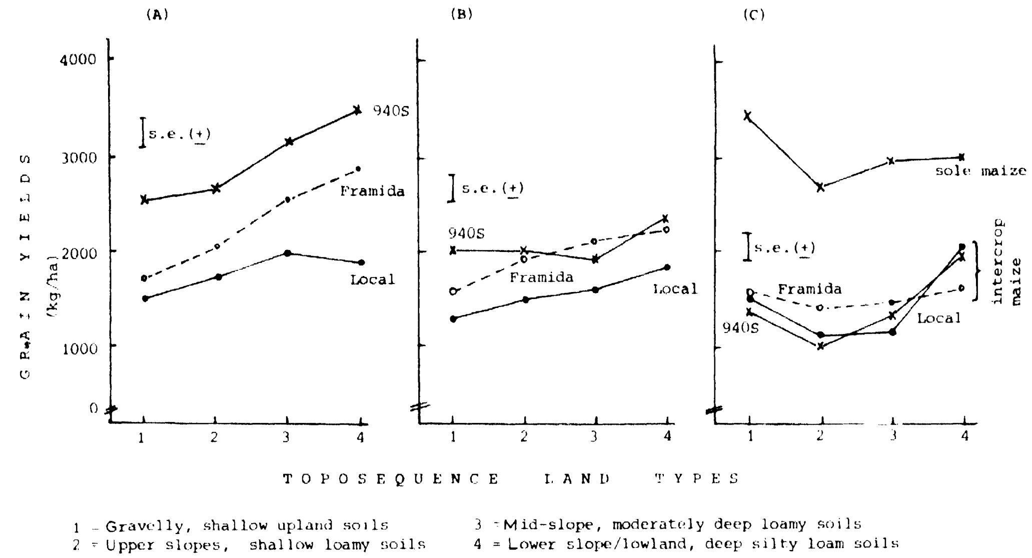

Fig. 3. Grain yield responses of three sorghum cultivars grown (A) as sole crop and (B) as intercrop with maize, and (C) maize intercrop yields as affected by sorghum cultivars, for different toposequence land types during the 1982 season.

intercrop situation, the two former cultivars maintained relatively higher and more stable yields across land types than when grown as sole crops (Fig. 3A and B).

The maize intercrop was not significantly affected by the different sorghum genotypes; it responded only slightly to the better soil moisture and fertility conditions of the lower slope and the better moisture infiltration conditions of the gravelly uplands in comparison with the crusting soils of the mid-slope (Fig. 3C). There was, however, a tendency for the maize intercrop to be more productive in combination with Framida than with the two other sorghums, particularly on the three highest, drought-prone, land types (Fig. 3C). The increased competitiveness for moisture of tillering sorghums (i.e., the Kamboinsé local and 940S) compared to non-tillering Framida may have contributed to this response.

The LER values for the different sorghum/maize systems indicated overall yield gains of 35% for the Kamboinsé local and Framida system, and of 18% for the 940S based system. Of the three cultivars, the yields of 940S (Table 5) suffered most from intercropping with maize, indicating that this cultivar is better suited for sole cropping than for intercropping. The tallness (4 m) of the Kamboinsé local was apparently not a critical factor for intercropping while the differences in competition gaps were insignificant, with maize flowering on 7 August, Framida and 940S on 3 September, and the Kamboinsé local only 4 days later.

Contrary to the results of the previous experiment, an increase in the maize

TABLE 5

Grain yields for three sorghum genotypes and for maize when intercropped in comparison with sole crop yields and corresponding LER values (Experiment 3; 1982)

	Sorghum grain yield (kg/ha)				Maize grain yield (kg/ha)		
	Intercrop[1]	Sole crop[2]	LER sorghum		Intercrop[1]	Sole crop[2]	LER maize
Sorghum cultivars	**	**		Maize cropping system with:	N.S.		
Kamboinsé local	1570	1800	0.87	Kamboinsé	1450		0.48
940S	2080	2990	0.70	940S	1440	3010	0.48
Framida	1970	2300	0.86	Framida	1510		0.50
s.e. (±)	95	105		s.e. (±)	102		
Cropping system (= plant density of competing maize)	N.S.			Plant density Maize intercrop	N.S.		
20 000 per ha	1980	—		20 000 per ha	1410	—	
40 000 per ha	1770	—		40 000 per ha	1520	—	
s.e. (±)	78			s.e. (±)	83		
Land type	**	**		Land type	*	N.S.	
Gravelly upland	1650	1930	0.85	Gravelly upland	1470	3420	0.43
Upper slope	1820	2160	0.84	Upper slope	1180	2700	0.44
Mid-slope	1880	2580	0.73	Mid-slope	1330	2970	0.45
Lower slope	2150	2770	0.77	Lower slope	1880	3010	0.63
s.e. (±)	155	172		s.e. (±)	166	438	
Interactions	N.S.	—		Interactions	N.S.	—	
C.V. (%)	20.3	17.8		C.V. (%)	27.8	29.1	

N.S.: non-significant.
*: significant F test at 1% level.
**: significant F test at 5% level.
[1]Total average plant population in intercrop: 70 000 per ha with sorghum population constant at 40 000 per ha.
[2]Total average plant population in sole crop: 60 000 per ha.

intercrop density did not significantly affect its yield nor was the sorghum intercrop yield significantly reduced (Table 5). In comparison with the 1981 season, this lack of response to increased density, also noticed for the first experiment, could be attributed to the drought in July 1982 (the 1981 rainfall had an unusually regular distribution).

Given the high incidence of droughts in the area, this result may indicate that it is desirable to maintain the maize intercrop population at levels below 40 000 plants/ha, certainly for the drought-prone uplands.

Sorghum/millet intercropping for upper and mid-slope fields (Experiment 4)

As discussed in Experiment 1, the available local millet cultivars are extremely competitive with sorghum; both are also photosensitive and suscep-

TABLE 6

Results of sorghum/millet intercropping trial for uplands, upper and mid-slope lands (Experiment 4; 1983)

	Grain yields (kg/ha)				LER		
	Intercrop		Sole crop		Sorghum	Millet	Total
	Sorghum	Millet	Sorghum	Millet			
Sorghum cultivars	**	*	N.S.[1]				
Kamboinsé local	800	210	1410	830	0.57	0.26	0.83
E35-1	1510	300	2120		0.71	0.36	1.07
s.e. (±)	141	22	268				
Cropping system	N.S.[1]	**		**			
Millet sowing delayed 9 days	970	410	-	1090	0.55	0.37	0.92
Millet sowing delayed 22 days	1340	100	-	570	0.76	0.18	0.94
s.e. (±)	141	22		54			
Supplemental nitrogen to millet	N.S.[1]	N.S.		*			
0 kg N/ha	1000	230	-	720	0.57	0.32	0.89
16 kg N/ha	1310	280	-	942	0.74	0.29	1.03
s.e. (±)	141	22		54			
Interactions	N.S.	N.S.	-	N.S.			
C.V. (%)	42.3	30.0	37.2	16.0			

N.S.: non-significant.
*: significant F test at 1% level.
**: significant F test at 5% level.
[1]: significant at 10% level.

tible to downy mildew when sown late, which can then result in low yields of either or both (Stoop et al., 1980). The present experiment tried to overcome these problems by delaying the sowing of Ex Bornu, an early-maturing, downy-mildew resistant millet cultivar, until the sorghum seedlings were established.

The trial suffered seriously from droughts in August just prior to sorghum flowering and also in September and October due to the early cessation of the rains. However, in spite of the resulting high variability, several significant responses were recorded (Table 6).

The relatively short-statured and slightly photosensitive E35-1 significantly outyielded the Kamboinsé local, but was also associated with significantly ($P<0.05$) higher millet intercrop yields. The sorghum intercrop yield responded ($P<0.1$) to both the delay in millet sowing and to the supplementary nitrogen applied to the millet intercrop. The results emphasize that the millet sowing should be delayed until the sorghum is well established and also that a 3-week delay in sowing reduces millet's yields to negligible levels. At lower sorghum densities, i.e., those commonly employed by farmers, the timing of millet sowing is likely to be less critical.

These preliminary data indicated that with the newly-introduced E35-1 which flowered at the same date as the Kamboinsé local, and with shorter and earlier-maturing millet genotypes, more productive sorghum/millet intercrop systems are possible than with the tall local sorghum and millet cultivars. Further experimentation with this intercrop system should involve other introduced sorghum cultivars of intermediate plant heights, sown at different densities, and followed by delayed sowings of a range of downy-mildew resistant millet cultivars with different maturation periods. The studies should thus establish the impact on sorghum yields of millets with lengthier maturities.

DISCUSSION AND CONCLUSIONS

Earlier experiments (ICRISAT, 1978, 1979) on sorghum/maize and sorghum/millet intercropping in the North Sudanian zone established that when both crops were sown at the same time, positive responses of 20% or more to intercropping could be obtained with the former system. In that case, full-season, photosensitive sorghum intercropped with early-maturing maize exploited the competition gap most effectively. However, in the sorghum/millet system, the millets (irrespective of their maturation period) always competed vigorously with sorghum for moisture and nutrients – as confirmed also by a 10 to 30% reduction in the leaf content of N, P, K, and Ca in the sorghum intercrop (ICRISAT, 1982).

The short 90 to 130-day growing season of the North Sudanian zone, which in addition tends to start and end more abruptly than in the wetter Southern zones, obviously offers less scope to exploit the competition gap between the components of a cereal/cereal intercropping system. Moreover, the two crop components generally have to be sown simultaneously in order to avoid further limiting the length of the growing season.

The increased availability from breeding programs of a wide array of crop cultivars of different maturation periods to some extent offers an opportunity to considerably manipulate competition gaps. In practice, however, the number of options proved fairly restricted because of the earlier-mentioned competition by millet intercrops, and various common pest and disease problems associated with many early maturing, non-photosensitive sorghum and millet cultivars. With respect to this factor, late-planted (July) sorghum is often attacked by shootfly (*Atherigona soccata*); early-flowering sorghum suffers from bird damage and grain mould and stimulates an early build up of midge (*Contarina sorghicola*) which then attacks the late-flowering sorghums. Similarly, late-planted millets may be attacked by downy mildew (*Sclerospora graminicola*), while early flowering, apart from serious bird damage, generally results in poor seedset due to pollenwash, poor seed quality due to ergot (*Claviceps fusiformis*), and other grain diseases. Although maize is more sensitive to drought stress than is millet or sorghum, it has fewer pest and disease problems, apart from a recent increase in the incidence of streak virus. Consequently, early maize cultivars (approximately 90 days to maturity) that flower in August, when the rains are most assured, have generally performed quite successfully.

The trials reported here, conducted against the above background, confirm the considerable potential of maize/sorghum intercrop systems for both the lower-slope and upper-slope landtypes. Thus yield gains of up to 50% were obtained from the combination of a 90-day maize with a 120-day, full-season, photosensitive sorghum when both were sown at the same time, the relative gains tending to increase towards the drier lands of the toposequence (Fig. 2). The sorghum component contributed most to this gain because of reduced intra-crop competition (as compared with the sole crop) during its final growth stage, which is completed on residual soil moisture. Likewise, the non-tillering, slightly photosensitive sorghum Framida proved less competitive than tillering, more leafy cultivars such as 940S and the Kamboinsé local, thereby increasing maize intercrop yields – particularly on the higher land types where drought stress is a common problem. Thus the optimum total plant density of the sorghum/maize intercrop and the stability of total yield across different land types were increased over those of the respective sole-crop plantings. This increased stability and potential for intensification are two features of the sorghum/maize intercrop systems that tend to remain generally valid, even with considerable variation in the annual rainfall and its distribution over the growing season.

In comparison, the sorghum/millet intercrop system offer relatively less scope for intensification than sorghum/maize systems; both sorghum and millet, because of pest and disease problems, have to mature in the post-rainy season when soil moisture is a constraint. Consequently, there is less scope to exploit a competition gap, nor could the sorghum/millet system support higher total plant densities than the sole crops. Moreover, millet intercrops of both early and late-maturing cultivars competed strongly with sorghum, even at millet plant densities as low as 10 000 plants/ha, when both crops were sown on the same date. The present studies indicated that this competition could be significantly reduced by delaying the millet sowing and that further improvements are possible with systems based on slightly photosensitive sorghums of intermediate height (± 2.5 m) rather than the tall local cultivars.

These results are particularly relevant to the earlier finding that slightly photosensitive sorghums sown in June are well adapted to upper-slope fields (Van Staveren and Stoop, 1985). For these fields, the total yield and its stability could be improved by a cropping system that allows for delayed sowing in July of downy-mildew resistant millet cultivars following the establishment of the earlier-sown sorghum, thereby compensating for sorghum plants lost during the common early droughts. A major benefit of such a system would be its increased production stability.

Fixed recommendations for the millet sowing in this system will be difficult to develop, since both sowing date and millet density will vary annually in response to the severity of the early-season drought damage inflicted on the sorghum sowings. However, this type of system and the sorghum and millet cultivars required for it clearly fulfill the objective of stabilizing production, by increasing the number of options available to farmers to respond to the unpredictable farming environment of the North Sudanian savanna zone.

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