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AGRONOMIC MANAGEMENT OF CEREAL/COWPEA CROPPING SYSTEMS FOR MAJOR TOPOSEQUENCE LAND TYPES IN THE WEST AFRICAN SAVANNA[1]

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ABSTRACT

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In the local agriculture of the West African Sudanian and Sahelian savanna zones, the major cereal crops are grown in patterns closely linked to major toposequence land types. Moreover, crops are commonly grown in intercrop combinations of which cereal/cowpea is the most widespread.

The present series of experiments investigates the impact of cereal density and of a cowpea intercrop on the grain yields of maize, sorghum, pearl millet, and several introduced sorghum genotypes. In all the studies, a spreading and photosensitive local cowpea cultivar was used.

In some seasons, even a low cowpea intercrop density of 5000 plants/ha could significantly reduce sorghum and maize yields on moisture-stressed soils, whilst with adequate soil moisture cereal yields were increased. The competitive effects of the cowpea intercrop, particularly on drought sensitive lands, were enhanced by increasing cowpea density, by lowering cereal density, by sorghum cultivars with relatively open leaf canopies (e.g., the local Guiniensis types) and by a relatively high phosphate status of the soil.

Because of the unpredictability of rainfall during the growth season and large local variations in soil fertility, high densities of cowpea and cereal would increase yield variation between locations and between years which is not beneficial for subsistence farmers. However, because of its positive effects on upland soil protection, and on cereal yields on moist lower slopes, a low cowpea intercrop density in the range of 2500 to 10000 plants/ha should have positive and stabilizing effects on cereal production in the long-term.

INTRODUCTION

Gradually undulating landscapes are a typical feature of most of the West African savanna zone. A previous article analysed how the soil proper-

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ties of the major land types in this landscape vary in response to their position in the toposequence (Stoop, 1985). Subsequent experiments on crop adaptation to various land types provided a scientific basis for the cropping pattern observed in the local agriculture, in which pearl millet is grown on the relatively poor and dry uplands, maize on the moist lower slopes and sorghum on the moist to wet lowlands (Van Staveren and Stoop, 1985).

West African farmers generally do not grow these principal cereal crops as sole crops; the crops do, however, occur in various mixtures (Steiner, 1982; Kabore et al., 1983) of which the cereal/cowpea mixture is the most widespread across different agro-ecological zones. In local farming, cowpea is intercropped with the cereal in very low densities (between 1000 to 3000 plants/ha) and is used as a vegetable, a grain crop and a fodder crop. Furthermore, the spreading local cowpea cultivars rapidly cover the soil thereby reducing soil erosion and runoff, besides fixing nitrogen and competing with weeds. Farmers using animal traction, tend to reduce or abandon the cowpea intercrop, since it interferes with their cultivation practices. However, towards the drier parts of the West African savanna (i.e., the North Sudanian and Sahelian zones) constraints on the use of draught animals increase (McIntire, 1983) and many farmers are likely to continue on a manual basis. Irrespective of mechanization, the cowpea intercrop serves many purposes several of which are associated with the stabilization of the soil environment.

Therefore, research into the dynamics of the cereal/cowpea system, its adaptation to toposequence land types and the possibilities of intensification appear to be justified, even though at present the system seems particularly well adapted to low fertility-low management conditions. Consequently the experiments are not primarily aimed at increasing yields, but rather at the identification of stable cropping systems relevant to small farmers operating under serious labour and capital constraints.

Intercropping in West Africa

Over the last decade, agricultural research has increasingly considered the cropping systems practised by farmers in the tropics. Technical scientists began to emphasize intercropping following on-farm studies by socio-economists (Norman et al., 1982). An extensive review of intercropping concepts and the technical problems involved in its experimentation was prepared by Willey (1979). However, while farmers emphasise the reduced risks and low labour requirements (Norman, 1974; Matlon, 1980), agronomists tend to emphasise the increased agricultural production potential of a few specific intercrop systems and experiment with high plant densities of management-responsive, improved cultivars.

In contrast, farmers in West Africa require a range of cropping systems to meet the large variability in the soils and land types and also as an insurance against large annual variations in rainfall. Since most farms are composed of several fields on different land types (Vierich and Stoop, 1985), comprehensive technologies are required which help stabilize and diversify crop production. For that purpose, the traditional (ecological) concept of matching crops to various land types which was discussed in earlier articles (Stoop et al., 1982; Van Staveren and Stoop, 1985) is useful. The local practice of carefully managing the interaction:

Land types (e.g., dry uplands and slopes, moist lower slopes, wet lowlands)	×	crops (including cropping systems)	×	cultural practices (e.g., land and water management, fertility management, sowing dates, plant density, weed control etc.)

greatly contributes to production stability, though absolute yield levels have remained low. Against this background, the present series of experiments was conducted in an effort to develop improved cropping systems which are more productive, but still consistent with farmers' production strategies.

Depending on the duration of the growing season and the moisture storage capacity of the soil, one can distinguish two major intercrop systems for areas with:

(a) a reliable growing season of 120 days or more, where the combination of two crops of different maturity cycles either as intercrops or relay crops is possible (for instance, a short-cycle 90 day crop with a full season 120 day crop, e.g. early millet with late millet; early maize with late sorghum or late millet; and early cowpea with late millet, etc.) or

(b) a reliable growing season of 80 days or less where relay cropping is no longer relevant and only combinations of crops with similar maturity cycles (around 90 days) are possible, such as millet/cowpea or sorghum/cowpea.

The availability of soil moisture is the critical factor in determining which of these systems is most appropriate in areas with a reliable growing season of between 80 and 120 days, i.e., the North Sudanian Zone. Consequently, intercropping patterns in that zone are closely linked to the land types of the toposequence. Moreover, it is a common practice in all the areas to delay sowing the second crop until the first is established, and also to sow seed mixtures to speed up the operation. Within the two cropping systems mentined above, one could distinguish between cereal/legume and cereal/cereal intercropping. The present article will focus on the former system and in particular that with cowpeas. The latter system will be discussed in a separate article.

Cereal/cowpea systems have proved to be among the most complicated for two reasons:

(a) The competitive balance between the cereal and cowpea components varies greatly in response to soil moisture and fertility conditions as they occur, for instance, along toposequences, and

(b) There are large interactions between cereal and cowpea crops such as caused by the degree of shading by the cereal.

As a result, the maturity cycles of the two crops, the spatial arrangement of the cereal hills, the canopy structure and tillering ability of the cereal are all likely to influence cowpea growth and thereby its competitiveness with the cereal. These complexities become particularly obvious when trying to intensify cereal/cowpea cropping systems by introducing improved cultivars (of different plant types) and by increasing the plant populations of the component crops.

Previous agronomic studies on cereal/cowpea systems have emphasized high plant populations of both crops, using improved cereal cultivars of short to intermediate plant height and prostrate or erect cowpeas in an attempt to raise the overall production substantially. Cowpeas, sown in separate rows, were either added to a full cereal stand (additive studies) or were replacing cereal rows (replacement studies). In both cases, the farmer's production objectives were not met because cereal yields were reduced, and the early season labour requirements for sowing increased as reported by Zoebl (1983) for maize/bean intercropping in Kenya. Moreover, any marked increase in the cowpea intercrop density tends to increase the incidence of pests (e.g. thrips (*Megalurothrips sjostedti*) and Maruca (*Maruca testulalis*)), which are difficult to control in intercrop situations despite the availability of insecticides and spraying equipment.

The present studies, therefore, attempted to modify the local cereal/cowpea systems for different land types by introducing improved sorghum cultivars, while maintaining an effective, but low population of the local spreading photosensitive cowpea. Earlier studies had shown that local cowpea cultivars tolerate lower soil phosphate levels than the improved cultivars (SAFGRAD/IITA, 1980). Furthermore, a rotation study showed that the residual effect of the local cowpea on millet was 25% greater than that of prostrate and erect cowpea cultivars in spite of the considerably greater plant density required to obtain a full soil coverage (Stoop and Van Staveren, 1983).

MATERIALS AND METHODS

The Kamboinsé research station (12°28′N; 1°33′W), where the experiments were conducted is about 10 km north of Ouagadougou in central Burkina Faso. Detailed information about the semiarid climate and the soil conditions were given in a previous article (Van Staveren and Stoop, 1985).

The total annual rainfall over the three year experimental period varied only from 700 mm in 1981, to 717 mm in 1982, and 663 mm in 1983; however, there were large and critical differences in its distribution (Fig.1). Over this period, five factorial type experiments, as summarized in Table 1, were conducted, to investigate the responses of cereal crops to agronomic management practices (i.e., cereal crop density; sowing date; cowpea intercropping) as influenced by land type. These land types change considerably along the toposequence. Thus, in a 100 m long field, the soils may vary from

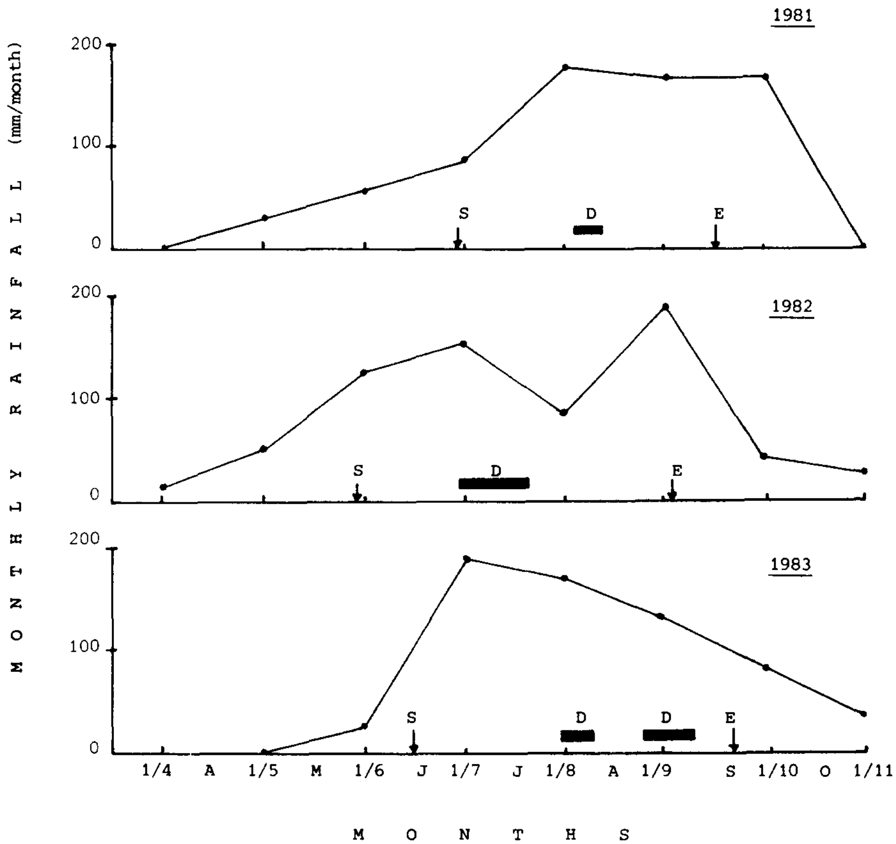

Fig.1. Monthly rainfall distribution at the Kamboinsé experiment station; annual variations in start (S) and end (E) of the rains are indicated and the occurrence of major droughts (D) over the period 1981 to 1983.

shallow (25 to 50 cm), gravelly soils in the highest part of the field, to deep, moist or even periodically wet soils in the lowest.

The 1981 experiments compared two different sorghum cultivars (Kamboinsé local and E35-1) sown at 40 000 and 80 000 plants/ha and grown as sole crops or with a cowpea intercrop (at 20 000 plants/ha). The resulting 2^3 factorial experiment was replicated on nine toposequence positions, equally shared between upper slope, lower slope, and lowland land types. For the two lowest land types (six toposequence positions), a maize experiment with the same cereal density and cowpea intercrop variables was included as a 2^2 factorial.

In the 1982 experiment, the impact of cowpea intercrop density (0; 5000; and 20 000 cowpea plants/ha) on sorghum was investigated in greater detail. In addition, this experiment combined two sorghum cultivars (940S and Framida), each grown at 40 000 and 80 000 plants/ha and sown at an early (18 June) and late (19 July) date. The resulting design was a $2^3 \times 3$

TABLE 1

Details of the three trials on crop management and cropping systems adaptation to land types

Trial year	Design	Cereal crops	Cereal cultivars	Cereal density (pl/ha)	Cereal/cowpea systems and additional cowpea density (pl/ha)	Sowing date(s)	Land types
1981	$2^3 \times 9$	Sorghum	Kamboinsé local	40 000	0	26 June	upper slope[1]
			E35-1	and	and		lower slope
	$2^2 \times 6$	Maize	J. Flint Saria	80 000	20 000		lowland
							lower slope
							lowland
1982	$2^3 \times 3 \times 4$	Sorghum	940S	40 000	0	18 June	upper slope[2]
			Framida	and	5000	19 July	mid slope
				80 000	20 000		lower slope
							lowland
1983	$2 \times 3^2 \times 4$	Sorghum	Kamboinsé local	40 000	0	17 June	upper slope[2]
			940S	and	5000		mid slope
			82S47	80 000	20 000		lower slope
	$2^2 \times 3 \times 4$	Millet	Kamboinsé local	20 000			lowland
			Didir local	and			
				40 000			

[1] For the 1981 trial, 3 replicates were used within each major land type; these were placed parallel to the contour lines and thereby exhibited slightly different soil moisture conditions. Consequently, statistical analyses were performed with 9 land types for sorghum and 6 for maize.
[2] For the 1982 and 1983 trials: the number of replicates equals the number of land types.

factorial which was repeated for the upper, mid and lower slope, as well as lowland land types (see Table 1).

Finally, in the 1983 season, one experiment combined three sorghum cultivars (Kamboinsé local, 940S, and 82S47) grown at two plant densities (40 000 and 80 000 plants/ha) with three cowpea intercrop densities (0; 5000; and 20 000 cowpea plants/ha). The resulting experiment was a 2×3^2 factorial which was repeated on the same four land types as in 1982. In addition, a comparison with millet was included utilizing two local cultivars (from Kamboinsé and Didir) grown at 20 000 and 40 000 plants/ha, while the cowpea intercrop treatments remained the same as in the sorghum experiment, the resulting design was a $2^2 \times 3$ factorial.

The experiments were analysed for each crop as a single replication, in order to estimate the various 'factor × land type' interactions. In the analyses of variance, the higher order interactions therefore were pooled to obtain an estimate of the residual error term, which was used in the F tests to indicate the statistically significant responses.

TABLE 2

General plant characteristics for maize, sorghum, millet, and cowpea cultivars recorded for upper and lower slope (moist) conditions; the days to 50% flowering for photosensitive cultivars occur between brackets, since these numbers will vary annually in response to the actual sowing date

Crops and cultivars	Plant type	Upper slope		Lower slope	
		Days to 50% flowering	Plant height (cm)	Days to 50% flowering	Plant height (cm)
Sorghum					
Kamboinsé local	photosensitive, tillering	(95)	368	(85)	406
940S	slightly photosensitive, tillering	94	195	81	239
82S47	slightly photosensitive, non-tillering	96	183	79	222
Framida	slightly photosensitive, non-tillering	81	238	79	252
E35-1	slightly photosensitive, non-tillering	75	213	74	242
Millet					
Kamboinsé local	photosensitive, tillering	(93)	268	(87)	367
Didir local	photosensitive, tillering	(94)	287	(87)	353
Maize					
J. Flint Saria	non-photosensitive, non-tillering	51	240	50	253
Cowpea					
Kamboinsé local	photosensitive, spreading	(72)	25	(70)	30

Though sorghum cultivars were changed over the years in response to the availability of new materials from the breeding programs, the experiments basically compared three contrasting plant types:

(a) photosensitive—tillering (local cultivars);

(b) slightly photosensitive—tillering (introduced cultivars);

(c) slightly photosensitive—non-tillering (introduced cultivars).

Further details of the plant characteristics are presented in Table 2.

The plot size was 4.5 × 5 m (i.e., 6 rows with 75 cm between rows); yield and crop measurements were based on the four central rows. Different land types were separated by drains, bunds and/or cultivated strips. The cowpeas were interplanted on the same day and on the same row (ridge) as the cereal. Fertilizer was applied at a uniform rate of 100 kg 14:23:15 NPK/ha after ploughing and before ridging and was followed 4 to 5 weeks after sowing by a side-dressing of 65 kg urea/ha to the cereal only. The urea was applied and incorporated into the soil at the time of the second hand-weeding.

RESULTS

Cereal yields as affected by cereal density and land types

The 1981 and 1983 experiments compared the adaptation of several sorghum cultivars, and of maize and millet to different land types; each crop was grown at a low and a high plant density. Though the total rainfall was below average in both years, its distribution over the season was favourable in 1981 and highly unfavourable in 1983 (Fig.1). In spite of these differences, some important trends occurred.

In 1981, the yield response to the favourable soil moisture conditions of

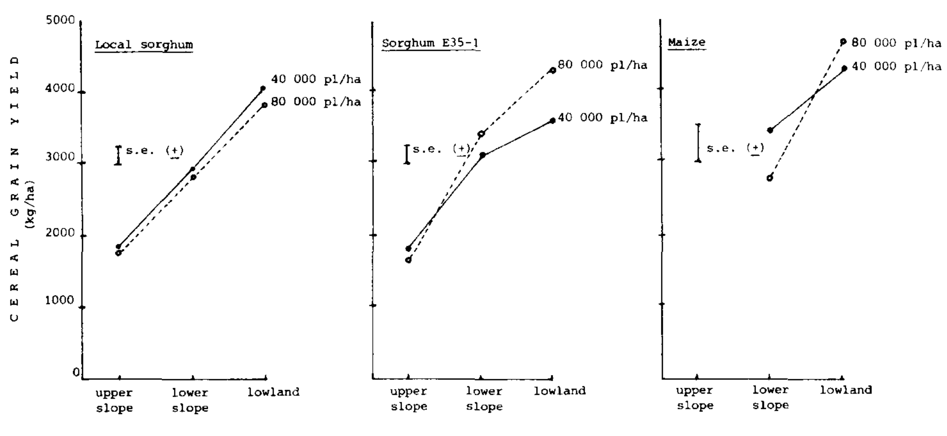

Fig.2. Grain yields for sorghum and maize in response to plant densities and to toposequence land types during the 1981 season.

the lower slopes and lowlands, was greatest for maize followed by the introduced sorghum E35-1 and the local sorghum (Fig.2 and Table 3).

In 1983, when all crops on the upper and mid-slopes were seriously damaged by drought, an even more dramatic yield response to the lower land types occurred (Table 4). The introduced sorghums 940S and 82S47, outyielded the local sorghum and millet on the two upper land types partly because of their earlier maturity. These cultivars were also the most responsive to the favourable lower slope conditions (Fig.3). In contrast to previous years, and as a result of the drought, the highest millet yields were obtained on the lower slopes, where it was, however, consistently outyielded by all the sorghum cultivars. The statistical significance (in 1981 at $P < 0.01$, in 1983 at $P < 0.05$) of the interaction between cultivar × land type, underlines the importance of the cultivar adaptation to land types.

TABLE 3

Sorghum and maize grain yield, in various cereal/cowpea cropping systems in response to toposequence land types (1981 trial)

	Sorghum grain yield (kg/ha)	Maize grain yield (kg/ha)
Sorghum cultivar (V)	N.S.	
Kamboinsé local	2890	—
E35-1	2990	—
s.e. (±)	63	
Cereal density (D)	N.S.	N.S.
40 000 pl/ha	2890	3890
80 000 pl/ha	2990	3720
s.e. (±)	63	245
Cropping systems (C)	N.S.	N.S.
Sole cereal	2930	3800
Cereal + 20 000 cowpea pl/ha	2950	3810
s.e. (±)	63	245
Land types (L)	**	*
Upper slope	1800	—
Lower slope	3090	2340
Lowland	3940	4510
s.e. (±)	133	424
Significant interactions	V × L (**) D × L (**) V × D (*) C × L (*)	C × D (*)
C.V. (%)	9.0	22.3

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

TABLE 4

Sorghum and millet grain yields in sole and cowpea intercrop systems (1983 trial)

Millet/Cowpea		Sorghum/Cowpea	
	Millet grain yield (kg/ha)		Sorghum grain yield (kg/ha)
Land types (L)	*	Land types (L)	**
Upper slope	200	Upper slope	490
Mid-slope	240	Mid-slope	490
Lower slope (dry)	900	Lower slope (dry)	1850
Lower slope (moist)	1260	Lower slope (moist)	3310
s.e. (±)	208	s.e. (±)	118
Cropping system (C)	N.S.	Cropping system (C)	N.S.
sole millet	670	sole sorghum	1510
millet + 5000 pl/ha cowpea	600	sorghum + 5000 pl/ha	1620
millet + 20 000 pl/ha cowpea	680	sorghum + 20 000 pl/ha	1470
s.e. (±)	180	s.e. (±)	102
Millet cultivar (V)	N.S.	Sorghum cultivar (V)	**
Kamboinsé local	720	Kamboinsé local	930
Didir local	580	940S	1840
		82S47	1840
s.e. (±)	147	s.e. (±)	102
Millet densities (D)	N.S.	Sorghum densities (D)	N.S.
20 000 pl/ha	710	40 000 pl/ha	1570
40 000 pl/ha	590	80 000 pl/ha	1490
s.e. (±)	147	s.e. (±)	84
Significant interactions	none	Significant interactions	L × V (*) V × D (*) L × V × D (*) L × V × C (*)
C.V. (%)	110.6	C.V. (%)	32.7

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

By changing the plant density, the above pattern was further reinforced. Millet grain yields decreased irrespective of the land type when the plant density was increased from 20 000 to 40 000 plants/ha. Though the 1983 experiment (Table 4) was conducted with tall local cultivars, similar trends were previously recorded for shorter introduced millets. Probably this response was related to the profuse tillering of millets, which in these experiments was further stimulated by relatively high nitrogen fertilizer applications.

The tillering, local sorghum responded somewhat similarly; in favourable years such as 1981, increased plant density had no significant impact on the yield (Fig.2), whilst in the unfavourable 1983 season, negative effects were recorded (Fig.3). In contrast, the behaviour of the management-responsive, introduced sorghum cultivars is more complex. This is illustrated especially by the non-tillering materials E35-1 in 1981, 82S47 in 1983, and to a lesser degree Framida in 1982. There were significant 'density X land type' interactions indicating higher optimum plant densities for the moist lower slope conditions, than for the upper slopes (Figs.2 and 3). However, the tillering cultivar 940S combines a high yield potential with a density response similar to that of the local sorghum (Fig.3), although in 1982, with an early season drought, it showed positive density responses on all the land types.

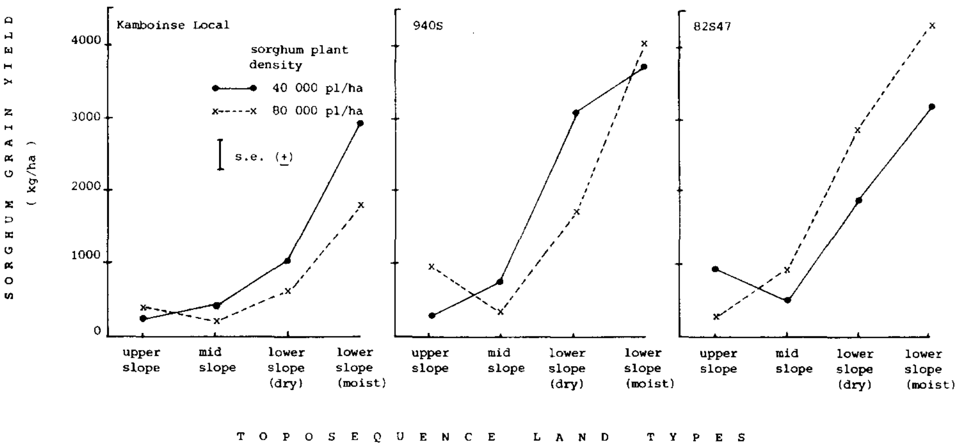

Fig.3. Sorghum grain yields (kg/ha) for three varieties in response to two plant densities and four land types at Kamboinsé (1983 season).

Finally, the plant density response for maize in 1981 (Fig.2), was rather similar to that for the non-tillering introduced sorghums, with a positive response to high density (80 000 plants/ha) on the lowlands.

Cereal yields as affected by cowpea intercrops and land types

The effects of cowpea intercrops on cereal yields also differed greatly between seasons, although certain responses were rather similar across the three very contrasting seasons.

The addition of a cowpea intercrop treatment at a density of 20 000 plants/ha in the 1981 experiment had no significant impact on the grain yields of the two sorghums (local and E35-1) grown on various land types. However, for maize, which is a more demanding crop, significant interactions between cropping system and maize density were recorded (Table 3). The cowpea intercrop effect on maize yield was positive in combination with high density, and negative with a low density maize planting; this effect would obviously be confounded with the interaction between maize densities and land types (Fig.2).

These latter effects were explored in more detail during the 1982 and 1983 experiments. The 1982 trial data for the tillering 940S and the non-tillering Framida are summarized in Table 5. The responses were similar to

TABLE 5

Sorghum grain yield (kg/ha) and cowpea intercrop forage yield (kg dry matter/ha) for the 1982 experiment

	Sorghum grain yield (kg/ha)	Cowpea forage (kg dry matter/ha)
Sorghum cultivar (V)	**	N.S.
940S	1800	350
Framida	1340	340
s.e. (±)	63	16
Sorghum density (D)	**	**
40 000 pl/ha	1320	400
80 000 pl/ha	1820	290
s.e. (±)	63	16
Sowing date (S)	**	**
18 June	2410	380
19 July	730	300
s.e. (±)	63	16
Cropping system (C)	*	**
sole sorghum	1640	—
sorghum + 5000 pl/ha cowpea	1700	170
sorghum + 20 000 pl/ha cowpea	1370	520
s.e. (±)	78	16
Land types (L)	**	**
Upper slope	1060	300
Mid-slope	1690	330
Lower slope (moist)	1790	430
Lowland	1740	320
s.e. (±)	90	23
Significant interactions	D × S (**) D × C (**) L × C (*) S × L × C (*)	S × L (*)
C.V. (%)	28.0	26.8

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

those for maize in 1981. Again, the interaction between cereal density and cropping system was highly significant ($P < 0.01$), suggesting that the cowpea intercrop becomes more competitive with sorghum, when the sorghum density is reduced (Fig.4). At a high sorghum density, however, the addition of a cowpea intercrop had a positive effect. These results were complemented by the significant interaction (at $P < 0.05$) between cropping system and land type, which was particularly relevant for the June sowing. The addition of a low density cowpea intercrop (5000 plants/ha) depressed sorghum yields on the upper and mid-slope land types, yet it had a positive effect for the two lowest land types (Fig.5). As usual, sorghum yields from the late sowing (i.e., in July) were much lower than for the early sowing (Table 5), whilst further yield losses also on the lower slopes were inflicted by intercropping with a high cowpea density.

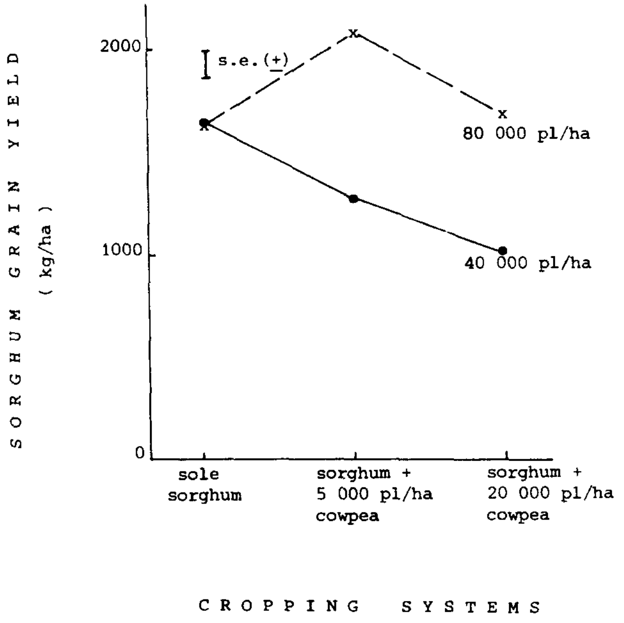

Fig.4. Interaction effect of sorghum plant density × cropping system on sorghum grain yields (1982 trial).

In spite of the drought which caused high variability in the data, the 1983 results again tended to confirm the earlier responses. As for the late planting in 1982, the crops failed on the drought-striken upper and mid-slopes (Table 4). However, because of the severe drought the negative effects of the cowpea intercrop recorded on the upper slopes in 1982 were now shifted to the lower slope, whereas a minor positive effect occurred only on the lowlands. A further analysis of the significant ($P < 0.05$) three factor interaction between sorghum cultivar, cropping system, and land type is presented in Fig.6 for the moist lower slope. It showed that a cow-

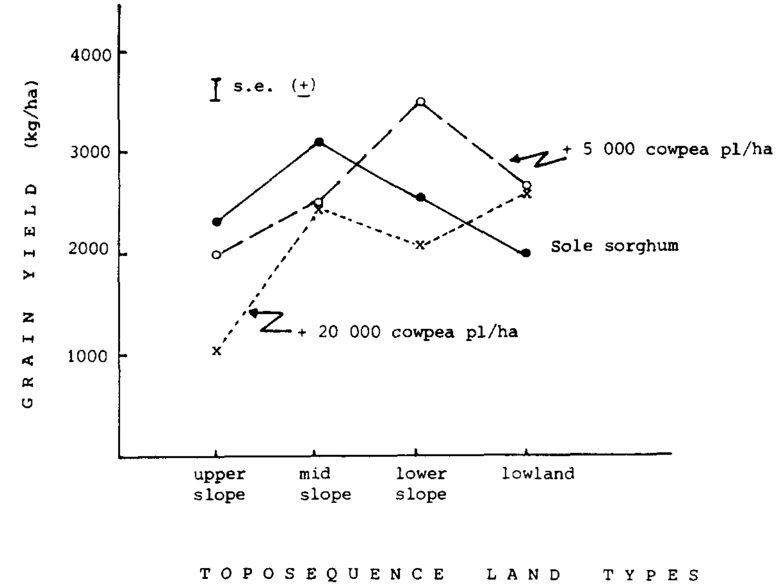

Fig.5. Sorghum grain yield responses from three sorghum/cowpea cropping systems recorded on four land types for the early (18 June) sowing during the 1982 season.

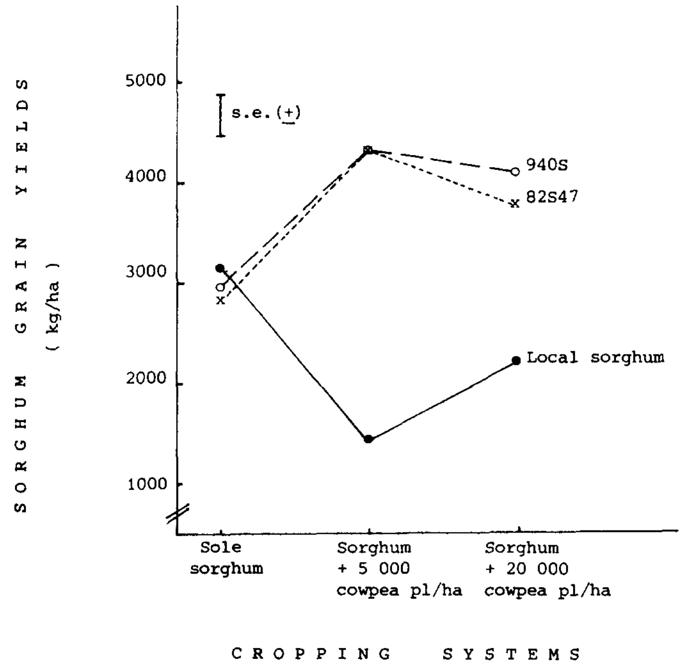

Fig.6. Interaction effects of sorghum genotype and cropping systems on sorghum grain yields obtained on a well-drained lower slope land type. (1983 trial).

pea intercrop can have a negative effect on a local sorghum cultivar with its more open canopy and longer maturity cycle, whilst the effect was positive for the introduced cultivars which matured 10 days earlier than the local and had denser canopies.

Insufficient evidence was obtained from the 1983 trial on millet/cowpea intercropping because of drought damage. Previous trials showed that of the three cereals, millet is by far the most competitive with cowpea, even at half the plant density commonly used for sorghum and maize. Consequently, cowpea intercrops generally had little effect on millet yield (though vice versa large effects were recorded). For example, in 1983, a cowpea intercrop of 5500 plants/ha reduced the yield of E35-1 sorghum by 33% but of millet by only 10% in the same trial on upland soils (ICRISAT, 1983).

Impact of cereal crops on cowpea intercrop forage production

The data on cowpea intercrop forage production have been summarized for the 1982 and 1983 experiments in Table 5 and Fig.7 respectively. In comparison with the cereals, the cowpea intercrop responded relatively little

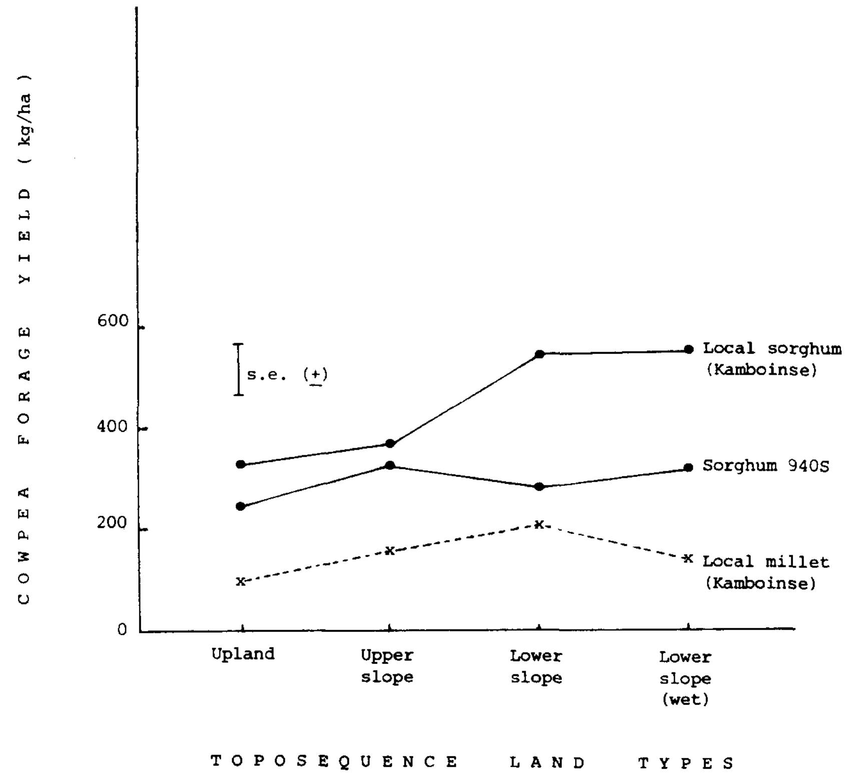

Fig. 7. Cowpea forage yield under sorghum (•——•) and millet (X---X) as influenced by crop variety; average plant density of sorghum 60 000 plants/ha and millet 30 000 plants/ha.

to the land types. Moreover, the cowpea crop proved least tolerant to temporary inundation and waterlogging, thus making it unadapted to the lowland part of the toposequence.

As expected, the density management of the cereal crop always had a highly significant impact on the cowpea forage production. With the high cereal density, cowpea forage yields were negligible for the millet/cowpea system, but were also greatly reduced under sorghums such as 940S. In this respect, the 1983 trial showed highly significant differences in cowpea forage production between the local sorghum with an open canopy and 940S with a dense canopy (Fig.7).

Finally, in both experiments a fourfold increase in the cowpea intercrop population generally increased its dry matter production by a factor of 2 to 3 only (Table 5). This response is linked to the spreading and photosensitive nature of the local cowpea cultivar and underlines its efficiency in providing a soil cover even when sown at low densities on the dry upland soils.

DISCUSSION AND CONCLUSIONS

The earlier information on the adaptation of millet, maize, and sorghum to different toposequence land types (Van Staveren and Stoop, 1985) was complemented by the present studies which revealed several significant two and three factor interactions between crops (or sorghum cultivars), cereal plant densities and land types. Based on these results, the following conclusions were drawn for the adaptation of different sorghum genotypes:

(a) there are significant differences in the adaptation of the different sorghum cultivars to major land types;

(b) optimum plant densities on the moist and wet lower slope lands are significantly higher than those for the drier uplands and slopes; and

(c) non-tillering cultivars tended to respond positively to increased plant density while the tillering cultivars (both local and introduced) responded less or not at all.

Consequently, the non-tillering cultivars required increasing plant densities towards the more humid lower slopes to equal the yield of the tillering cultivars, e.g., 940S sown at a uniform low density. These results further emphasise the relative merit of high yielding, slightly photosensitive, tillering materials of the 940S type. A longer optimum sowing period than for non-photosensitive materials and a relatively low optimum plant density which was more independent of land type than for the non-tillering cultivars, should make these tillering materials attractive to large groups of both mechanised and manual farmers.

The second factor studied was the impact of a cowpea intercrop on cereal production. In line with farmers' production objectives, that is a stable yield of the main cereal crop, with minimal early season labour requirements (Matlon, 1980; Jodha, 1981), no efforts were made to maximize the yields from the cowpea component. Instead, it was attempted to minimise its competitiveness with the cereal, whilst maintaining the advantage of good and rapid soil coverage by using a local, spreading cowpea cultivar. Two field observations repeated over several seasons were of major significance:

(a) cowpea generally did not tolerate flooding or waterlogging for any length of time and

(b) a crop cover of cowpea greatly reduced the common crusting problem of the soils on the uplands and slopes.

Thus, except for the periodically inundated lowlands, cereal/cowpea systems are important for all the land types of the toposequence; but most for the uplands and slopes where a cowpea cover will reduce the erosion and runoff problem by improving moisture infiltration. However, because of the drought risks on most uplands, cereal/cowpea systems require careful adjustment of cereal and cowpea densities when attempting to increase production.

On upland soils, a cowpea intercrop can significantly reduce sorghum and maize yields, and to a lesser extent millet yield, even at a density of only 5000 plants/ha. On the humid lowlands, however, it caused significant increases in sorghum yields in both 1982 and 1983, and for maize in 1981. In most cases, a cowpea intercrop sown at 20 000 plants/ha was detrimental to cereal yields except on the lowest land types, where it had no significant impact. This clearly indicates that cowpea intercrop densities can be increased with increasing soil moisture availability. When spreading cowpea cultivars are used, densities above 10 000 plants/ha will not be useful, whilst on the relatively dry uplands cowpea densities should not exceed 5000 plants/ha.

These conclusions are supported by the results from on-farm trials (Matlon, 1984), in which a rather sharply-defined optimum around 6000 cowpea plants/ha was recorded for two locations in the North Sudanian zone. The optimum was less critical and considerably higher (15 000 to 20 000 plants/ha) for the wetter South Sudanian zone of Burkina Faso. The same study also confirmed that fertilizer applications greatly stimulated the vegetative growth of cowpeas and thereby their competitiveness with the cereal crop; as a result, the optimum density for cowpea was lower. This phenomenon clarifies why Matlon found somewhat higher optimum cowpea densities under on-farm conditions, which were generally less fertile than the experiment station fields. By comparison, millet systems for the uplands would support higher densities of a cowpea intercrop than the sorghum-based system.

This sensitive balance between the cereal crop and the cowpea intercrop as influenced by soil fertility and fertilizer applications (particularly nitrogen and/or phosphate) becomes even more critical when both crops are sown at relatively high density, or when the sowing of one of the crops is delayed by only a few days (as reported also for maize/bean intercrop systems by Francis et al., 1982).

Besides soil fertility, the vegetative development of cowpea and thereby its competitive ability was also increased when this crop intercepted more light. This occurred at lower cereal densities and with cereal cultivars with a more open canopy structure. Consequently, a cowpea intercrop density of 5000 plants/ha reduced the yields of local sorghum, whilst it substantially increased the yields of sorghum cultivars with dense canopies such as 940S and 82S47 (Fig.6). Possibly, the positive cowpea effect on the introduced sorghums and maize under the humid lower slope conditions could be related to a greater availability of biologically fixed nitrogen from the cowpea once this crop was shaded following the closure of the cereal canopy.

Clearly, cereal/cowpea systems are well adapted to the uplands and slopes of the Sahelian and Sudanian zones. The scope for intensification however, is greatest for the humid lower slopes, when using improved sorghum cultivars. This latter conclusion is similar to that of Andrews (1974) who worked under the higher rainfall regime of northern Nigeria.

The present study has placed emphasis on cropping systems based on a full cereal planting with the cowpea intercrop as a secondary component, which is in line with local farmers' production objectives. The study clearly showed that both the optimum cereal plant density, as well as cowpea intercrop density require considerable adjustments in response to land types, but will also be affected by annual rainfall and its distribution.

Moreover, optimum plant densities will differ significantly in response to plant types, i.e., tillering ability, canopy structure, and maturity cycle for the cereals and spreading, prostrate or erect growth habits for cowpeas (Stoop and Van Staveren, 1983). Consequently recommendations developed for cereal/cowpea intercrop systems will tend to vary considerably among major cereals and require a considerable degree of fine-tuning to meet local conditions. In that respect, the present study showed some of the major interactions involved and thereby the directions in which recommendations will require adjustments upon implementation by extension agents and farmers.

REFERENCES

Andrews, D.J., 1974. Responses of sorghum varieties in intercropping. Exp. Agric., 10: 57—63.

Francis, C.A., Prager, M. and Tejada, G., 1982. Effects of relative planting dates in bean (*Phaseolus vulgaris* L.) and maize (*Zea mays* L.) intercropping patterns. Field Crops Res., 5: 45—54.

ICRISAT, 1983. Annual Report Upper Volta. Agronomy section. ICRISAT/PNUD, B.P. 1165, Ouagadougou, Burkina Faso, pp. E1—42.

Jodha, N.S., 1981. Intercropping in traditional farming systems. In: Proc. Int. Workshop on Intercropping 10—13 Jan 1979. ICRISAT, Patancheru P.O., Andhra Pradesh 502—324, India, pp. 282—291.

Kabore, P.D., Lebenne, Y. and Matlon, P.J., 1983. Modèles de culture dans trois zones agro-climatiques de Haute Volta. ICRISAT West Africa Economics Program; Report No. 9, Ouagadougou, Burkina Faso, 34 pp.

Matlon, P.J., 1980. Local varieties, planting strategies, and early season farming activities in two villages of Central Upper Volta. ICRISAT West Africa Economics Program. Progress Report 2, Ouagadougou, Burkina Faso, 53 pp.

Matlon, P.J., 1984. Technology evaluation: five case studies from West Africa. In: Coming Full Circle: Farmers' participation in the development of technology. IDRC, Ottawa, Canada, pp. 95—118.

McIntire, J., 1983. Two aspects of farming in SAT. Upper Volta: animal traction and mixed cropping. ICRISAT West Africa Economics Program. Progress Report 7, Ouagadougou, Burkina Faso, 48 pp.

Norman, D.W., 1974. Rationalizing mixed cropping under indigenous conditions. The example of northern Nigeria. J. Dev. Studies, 11: 3—21.

Norman, D.W., Simmons, E.B. and Hays, H.M., 1982. Farming Systems in the Nigerian Savanna — Research and Strategies for Development. Westview Press, Boulder, CO, 275 pp.

SAFGRAD/IITA, 1980. Annual Report. Cowpea improvement section. SAFGRAD, B.P. 1783, Ouagadougou, Burkina Faso, pp. C1-76.

Steiner, K.G., 1982. Intercropping in tropical smallholder agriculture with special reference to West Africa. GTZ, No. 137; GTZ, Eschborn, Germany, 303 pp.

Stoop, W.A., 1985. Variations in soil properties along toposequences in the West African Savanna; implications for the development of improved cropping systems. ICRISAT, Patancheru, P.O., Andhra Pradesh 502—324, India, 53 pp. (Restricted distribution; available upon request).

Stoop, W.A., Pattanayak, C.M., Matlon, P.J. and Root, W.R., 1982. A strategy to raise the productivity of subsistence farming systems in the West African semiarid tropics. In: Sorghum in the Eighties. Proc. Int. Symp. on Sorghum, 2—7 Nov. 1981. ICRISAT, Patancheru, P.O., Andhra Pradesh 502—324, India, pp. 519—526.

Stoop, W.A. and Van Staveren, J.P., 1983. Effect of cowpeas in cereal rotations on subsequent crop yields under semiarid conditions in Upper Volta. In: Biological Nitrogen Fixation Technology for Tropical Agriculture, CIAT, Cali, Colombia, pp. 653—657.

Van Staveren, J.P. and Stoop, W.A., 1985. Adaptation to toposequence land types in West Africa of different sorghum genotypes in comparison with local cultivars of sorghum, millet and maize. Field Crops Res., 11: 13—35.

Vierich, H.I.D. and Stoop, W.A., 1985. Ongoing changes in the West African Savanna Agriculture (as affected by increasing population pressure and continuing low rainfall). ICRISAT West Africa Economics Program. Ouagadougou, Burkina Faso. (Restricted distribution; available upon request.)

Willey, R.W., 1979. Intercropping; its importance and research needs. Part 1: Competition and yield advantages. Field Crops Abstr., 32: 1—10. Part 2: Agronomy and research approaches. Field Crops Abstr., 32: 73—85.

Zoebl, D., 1983. Scope for GLP seeds: the views of a farming systems economist. Kenya Farmer, August 1983: 24—25.