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ADAPTATION TO TOPOSEQUENCE LAND TYPES IN WEST AFRICA OF DIFFERENT SORGHUM GENOTYPES IN COMPARISON WITH LOCAL CULTIVARS OF SORGHUM, MILLET, AND MAIZE

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ABSTRACT

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Gently undulating landscapes are typical for large parts of the Sudanian and Sahelian zones of the West African semiarid tropics. Within this landscape a pattern of land types and soils, which is closely linked to the topography, can be distinguished. Thus low fertility drought sensitive soils (Alfisols) are found on uplands, whereas the more fertile soils of the lower slopes and lowlands (mainly Inceptisols) will be moist to wet. In response to these variations in land types and the unpredictable rainfall, which can cause both droughts and floods during the rainy season, the subsistence farmers have adopted distinct cropping patterns in order to minimize the risk of crop failure under the conditions of a low input agriculture. Consequently, cropping patterns which closely follow the toposequence have evolved, with millets grown on dry uplands and slopes, maize on moist lower slopes, sorghum on lower slopes, and rice on lowlands.

The present study was conducted mainly in Upper Volta and provides a scientific basis for these cropping patterns by analysing the responses of three major cereal crops to land types and to sowing dates. Next, several high yielding, introduced, sorghum cultivars were tested to determine their adaptation to the local conditions and to formulate plant characteristics useful to plant breeders in selecting improved cultivars which would best meet the requirements of the local agriculture.

It was concluded that to meet the large diversity in land types and rainfall conditions typical for the West African semiarid tropics, even an advanced type agriculture would require a range of technological options, in terms of improved varieties and cultural practices. Consequently, the likelihood that a single improved cultivar could replace the local cultivars is remote, as is the possibility of introducing a standard technological package.

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INTRODUCTION

In most of the West African semiarid tropics farming is mainly at the subsistence level and based on hand labour. Early season labour requirements for seeding and weeding of crops, therefore, form a serious bottleneck for increased food crop production (Norman, 1975; Matlon, 1980). Although animal traction has improved the speed of land preparation and seeding in several areas, timeliness of operations remains a constraint. This is compounded by the large drought risks at the beginning of the season, which may not only cause delays in other field operations but may also make it necessary to reseed.

In order to minimize these drought risks, and also to spread the early season labour requirements more evenly, farmers have traditionally practised a sequence of activities in which certain crops were planted on certain land types dependent also on the actual starting date of the rains (Matlon, 1980). These land types are generally linked to distinct positions in the topography and often with specific soil types and soil moisture regimes, thus forming so-called 'toposequences' (Moormann et al., 1977; Veldkamp, 1979). The utilization of this systematic soil variation in toposequences is a key element of the local farming strategy and a major factor responsible for the high degree of yield stability of local farms, though the overall productivity for cereals remains low (in the order of 300–500 kg grain/ha).

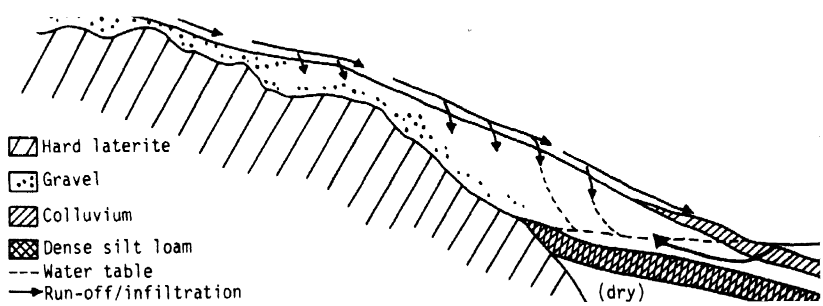
In the past, agricultural research has dealt mainly with the problem of low yields of specific crops, whereas yield stability and the interrelationship between different crops grown on a single farm have been given less consideration. The research presented in this paper concerns the interaction between various cereal crops, land types, and sowing dates. The major aims of the study were to increase productivity, while maintaining the yield stability of the subsistence systems, by identifying the optimum growth conditions for local cereals in comparison with a range of introduced sorghum cultivars. In this way, an important connection was established between on-station research and the off-station farming systems strategy discussed in an earlier paper (Stoop et al., 1980). Moreover, the results emphasize the need for a range of different cereal cultivars (e.g., in terms of maturity) to fit not only the major agroclimatic zones, but also the major toposequence land types. Consequently, plant breeders and agronomists should be able to formulate the various breeding objectives more clearly (see also Figure 11).

The investigations were carried out mainly at the Kamboinse experimental station near Ouagadougou in Upper Volta under the West African Cooperative program of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and are part of a larger study to develop improved cropping systems, the results of which will be reported in subsequent papers.

TOPOSEQUENCE CONCEPT AND EXPERIMENTAL OBJECTIVES

Many parts of semiarid West Africa have been transformed by geomorphologic evolution (peneplanization) into the present undulating landscape with gentle slopes and soils which vary considerably over short distances.

Basically, two types of soil variability can be distinguished in this environment. The first is the systematic variability which is generally linked to the topography (Leveque, 1969; Boulet, 1978; Moormann and Kang, 1978; Stoop and Pattanayak, 1980) and is shown by the schematic representation of the toposequence at the Kamboinse experimental station (Fig. 1). The systematic soil variability originated mainly from differences in soil moisture regimes along slopes, as reported also by Hanna et al. (1982). The second type of variability is that which occurs randomly and is mainly associated with the varying depths of the shallow upland soils over the bedrock.



Land type	Plateau/Uplands	Upper slope	Mid-slope	Lower slope/Lowlands	Swamp
Colour topsoil	brown to dark brown	dark brown	dark yellowish brown	dark greyish brown	
Texture topsoil	gravelly sandy loam	sandy loam	sandy loam	silty loam	
Depth of profile over laterite (cm)	35	80	>120		
Depth of profile over dense silt-loam layer (cm)			100	95	
Depth of groundwater				variable (infrequent inundation)	variable (periodic inundation)
Prevailing crop	millet	millet	millet/sorghum	sorghum/maize	rice
soil classification	Plinthustalf	Oxic Paleustalf	Oxic Paleustalf	Tropaquept	

Fig. 1. Schematic presentation of soil conditions, soil water movement and cropping along the Kamboinse toposequence.

The major land types also have greatly different land and water management and fertilization requirements. For instance, the soils of the uplands, upper and mid slopes are most subject to droughts and their agricultural potential will mainly depend on soil depth (i.e., water availability) and the physical properties of the top soil (susceptibility to erosion and crusting).

When continuously cropped, without regular applications of manure, a decline in soil productivity will readily occur. Decomposition of organic matter and consequently a loss in cation exchange capacity and exchangeable cations, in addition to an increased bulk density are major factors responsible for this loss in soil fertility (Charreau and Fauck, 1970; Charreau and Nicou, 1971; Jones, 1971; Siband, 1972; Roose, 1979). For these light textured soils serious acidification due to regular ammonium sulfate and/or urea application has been reported (Siband, 1974; Jones, 1976; Pieri, 1976).

In contrast, the deep soils of the lower slopes bordering the swamps have a higher organic matter content, can store more residual moisture and may benefit from a supplementary lateral water flow through the soil from upland to lowland. During the rainy season temporary inundation for periods varying from a few days (lower slopes) to several months (the swamp areas) will normally occur.

In Upper Volta, the upland soils, mostly Alfisols, represent about 65% of the soils in the 650—850 mm rainfall zone; the lowland soils (generally Inceptisols) cover approximately 30% of the land (Boulet, 1976).

Local farmers exploit this soil variability by matching it with the requirements of their major crops. Thus, in general pearl millet is grown on the dry upland soils, sorghum on the moist to wet lower slopes, and rice in the lowlands. Initial investigations (Figs. 4 and 5) have shown that these interactions between crop and soil type are of such magnitude that they should not be ignored when new, improved, cultivars are tested and introduced.

The variability of soils within small areas often interferes with agricultural experimentation and leads to high coefficients of variation even with increased replication. However, the systematic variability can be efficiently exploited by having one or more replications on each of the major land types. In this way, various interaction effects between land type and agronomic variables (e.g., cultivars, sowing dates, plant densities and fertilizers) on crop production can be quantified at one single site under a single rainfall regime. Especially in the semiarid tropics with its very localized showers, the latter aspect becomes important. Summarizing, the major objectives of the present toposequence studies are:

(1) to evaluate the response of major local cereal crops (sorghum, millet and maize) and their introduced cultivars to the most common environmental stresses, i.e., moisture stress on shallow upland soils and temporary waterlogging on lowland soils;
(2) to identify the optimum soil conditions (i.e., land type) for introduced cultivars;
(3) to formulate agronomic recommendations for the optimum sowing dates of introduced cultivars to minimize the risk of crop failure given the unpredictability of particularly the early rains.

MATERIALS AND METHODS

Experimental sites

Most of the reported results were obtained at the Kamboinse experimental station (12°28'N; 1°33'W) which is about 10 km north of Ouagadougou in

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Central Upper Volta. Some results from toposequence studies in Baramandougou, (13°17′N; 4°54′W) 40 km northeast of San along the Bani river in Mali have also been included.

Climate

Based on rainfall patterns, the West African savanna region can be subdivided into three broad ecological zones (Kowal and Kassam, 1978). In the north, the Sahelian zone with less than 650 mm annual rainfall and a rainy season of 2 1/2—4 months, followed by the North Sudanian zone with 650—1000 mm and 4—5 months of rain, and finally in the south, the South Sudanian zone with more than 1000 mm and 5—6 months of rain (Fig. 2). Thus, towards the south rainfall will increase and its distribution will become less erratic than in the north (Virmani et al., 1980). However, the start of the season and the subsequent early rains, tend to be unpredictable throughout the region.

The studies were conducted in the 700—850 mm rainfall zone (North Sudanian zone). For the Ouagadougou area there is a probability that in one year out of four the rains will start before the first week of June; however,

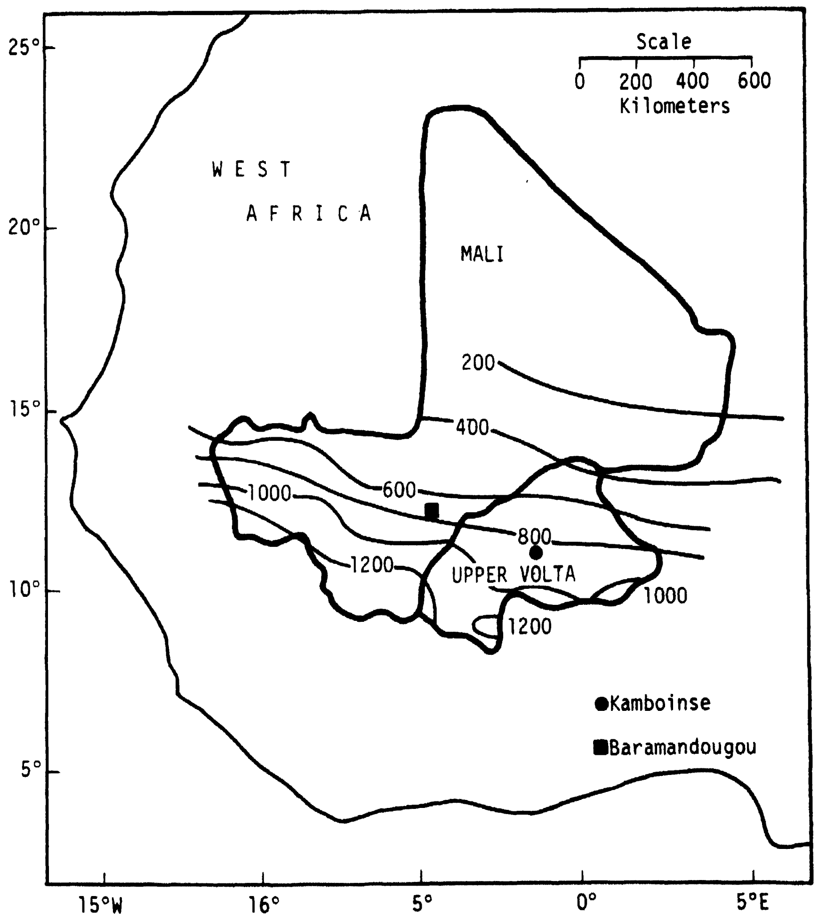

Fig. 2. Annual rainfall (Isohyets in mm) for Upper Volta and Mali (Virmani et al., 1980).

the same probability holds for the last week of June, or later (Baldy, 1977, personal communication). Moreover, it is quite common, when the rains start in early June (>20 mm/week), for the later part of that month, and the beginning of July to be dry. The rains in July, August, and early September tend to be fairly regular, although both droughts and floods may occur. The end of the rains generally comes abruptly by mid-September and the probability of rain in October is very small (see also Table 1). Other general climatic data for Kamboinse have been presented in Fig. 3. A similar pattern occurs for the Baramandougou site.

TABLE 1

Rainfall characteristics over the period 1954—1976 (in mm), Kamboinse, Upper Volta

Probabilities	J	F	M	A	M	J	J	A	S	O	N	D	Total/ year
Minimum	0	0	0	tr	12	52	112	143	63	0	0	0	577.1
90%	0	0	0	0.3	23	61	119	164	78	2.3	0	0	694.2
75%	0	0	0	3.2	39	92	134	189	100	5.4	0	0	792.1
median	0	0	tr	10.4	68	114	171	242	146	44.5	0	0	823.3
mean	0.1	4.5	3.7	17.3	66	121	181	251	151	41.4	1.1	1.3	838.5
25%	0	2.7	4.0	27.3	81	162	211	293	190	65.6	tr	tr	914.1
10%	0.5	22.0	15.4	50.8	98	182	265	344	228	102.4	7.3	4.8	1001.5
maximum	1.9	45.0	23.7	73.6	154	207	315	423	295	125.1	9.1	18.4	1091.3

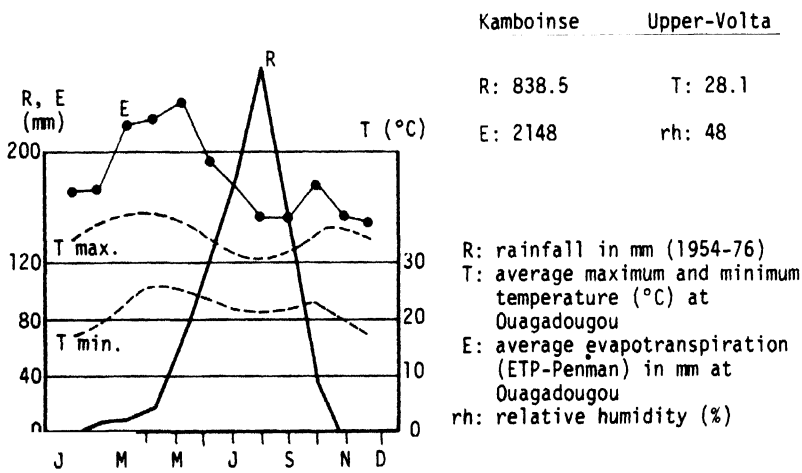

Fig. 3. Some climatic characteristics for Kamboinse, Upper Volta.

Soils

Specific data for the three major soils present along the toposequences at the Kamboinse and Baramandougou experiment stations are shown in Fig. 1 and in Table 2.

TABLE 2

Properties of the soils in the three major land types represented in the toposequence at Kamboinse (Upper Volta) and Baramandougou (Mali)

Location	Soil depth (cm)	pH H_2O	pH KCl	Texture		Bulk density (g/cm^3)	Organic matter (%)	CEC (me/100g soil)	Exch. cations (me/100g soil)			P-Olsen (ppm)
				% sand	% clay				Ca	Mg	K	
Kamboinse												
Upper slope	0–15	6.3	4.9	58	15	1.6	0.85	5.2	1.7	0.5	0.2	4.7
	30–50	6.4	5.0	30	35	1.4	0.16	7.1	3.2	0.8	0.2	1.0
Lower slope	0–15	6.3	5.0	52	10	1.6	0.75	5.1	2.1	0.6	0.2	1.1
	30–50	6.4	5.0	39	26	1.5	0.36	6.6	2.9	1.0	0.2	0.3
Lowland	0–15	6.5	5.2	32	16	1.5	1.36	5.5	4.3	1.0	0.1	1.3
	30–50	6.6	5.2	30	27	1.6	0.53	5.3	3.9	1.2	0.2	0.6
Baramandougou												
Upper slope	0–15	5.1	3.8	76	15	1.5	0.64	4.6	0.3	0.2	0.2	1.2
	30–50	5.6	4.1	62	26	1.6	0.50	6.4	2.0	1.0	0.1	0.5
Lower slope	0–15	4.8	3.8	76	14	1.5	0.48	4.1	0.2	0.2	0.1	0.7
	30–50	5.1	4.0	71	17	1.5	0.23	4.1	0.9	0.5	0.1	0.5
Lowland	0–15	5.2	4.1	79	7	1.6	0.55	2.9	0.7	0.4	0.2	1.2
	30–50	5.7	4.3	65	20	1.5	0.38	5.5	1.6	1.0	0.1	0.4

At Kamboinse the soils form a continuum and change gradually over a distance of 100 m from a shallow gravelly loam soil over hard laterite on the uplands, to sandy loam soils of intermediate depth (80 cm) over a dense clay loam subhorizon near the swamp. The non-gravelly soils of the upper and mid slopes have a sandy loam (58% sand, 15% clay) texture and low organic matter content. Consequently, serious crusting occurs upon drying, which causes low water infiltration rates and serious run-off together with erosion. By contrast, the soils of the lower slopes are colluvial, with relatively more silt and less clay than the upland soils; their organic matter content and overall fertility tend also to be greater. The problem of surface crusting is less, but the available-water holding capacity is still fairly low (70 mm) because of an impermeable clay loam subhorizon. However, moisture stress on these soils is rare because of the proximity of a swamp; which may result in periodic waterlogging or even inundation (Fig. 1).

In comparison, the Baramandougou toposequence is less fertile (lower pH and more sandy textures than at Kamboinse) and has probably been recently affected by erosion, and subsequent sedimentation on the lowlands (Table 2). These soils are less subject to crusting because of their high sand content (around 75%) and consequently infiltration rates appear to be higher. This has caused a marked lateral waterflow through the subsoil from uplands to lowlands, which compensates for the low available-moisture holding capacities (about 35 mm) of these rather shallow soils.

There are thus four major land types; uplands with shallow gravelly soils; upper and middle slopes often with shallow though non-gravelly soils; lower slopes with relatively deep, moist colluvial soils; and finally, lowlands also with deep soils, subject to infrequent inundation.

At both locations, soil fertility as measured by exchangeable cations and available phosphate was very low (Table 2).

Crops and crop cultivars

The investigations were carried out with pearl millet (*Pennisetum americanum*), sorghum (*Sorghum bicolor*) and maize (*Zea mays*), the major cereal crops adapted to the 700—850 mm rainfall zone. The local, photosensitive cultivars of sorghum and millet were included, as well as the locally selected, non-photosensitive, early maize. In addition, four promising, introduced, sorghum cultivars were tested: the slightly photosensitive E 35-1 and 940S, and the non-photosensitive 38-3 and VS 702. These represent major categories of cultivars with respect to maturity, plant height, tillering ability, and panicle type (Table 3).

Experimental design and general management procedures

In the exploratory experiments at Kamboinse (1977 and 1978) continuous 80-m long strips from the upper slope to the lowland were used (see

TABLE 3

Some general data on crop and crop cultivars used in various experiments

Variety	Plant type	Panicle type	Plant height (cm)	Approximate no. of days to harvest
Sorghums				
Local white Kamboinse	Strongly photosensitive, tillering	loose	385	> 120[a]
940 S	Slightly photosensitive; tillering	compact	200	> 110[a]
E 35-1	Slightly photosensitive; non-tillering	compact	195	120
38-3	Non-photosensitive; non-tillering	compact	200	115
VS 702	Non-photosensitive; non-tillering	semi-compact	110	105
Millet				
Local Kamboinse	Strongly photosensitive; tillering	25 cm	350	> 120[a]
Maize				
Improved Local Jaune Flint de Saria	Non-photosensitive	—	185	90

[a] Exact cycle depends on the sowing date.

Fig. 1); each strip was sown to a different crop using local cultivars. The strips were subdivided into subplots of 3.5 X 6 m, thus forming a continuous function type design for which yield data were recorded (see Figs. 4 and 5).

For the experiments conducted in 1979, four contrasting land types (mainly based on different soil moisture regimes) were selected in Kamboinse and three in Baramandougou and a split-plot type design was used. Each land type was considered as a major block within which factorial combinations of crops and/or crop cultivars and dates of sowing were randomized and replicated three times. The trial was conducted with local cultivars of sorghum, millet, and improved local maize; as well as two introduced sorghum cultivars: E 35-1 and VS 702.

In 1980, a similar trial was conducted in Kamboinse, combining three sorghum cultivars (local, 940S, and 38-3) with three sowing dates.

The plot size was 5 X 6 m and the different soil types were separated by drains, bunds, and/or cropped strips. Planting was done on the side of ridges, which were 75 cm apart. Plant populations ranged from 22 500 plants/ha for local millet, to 45 000 plants/ha for local sorghum, and 60 000 plants/ha for the introduced sorghums and for maize. Fertilizer was applied at a standard

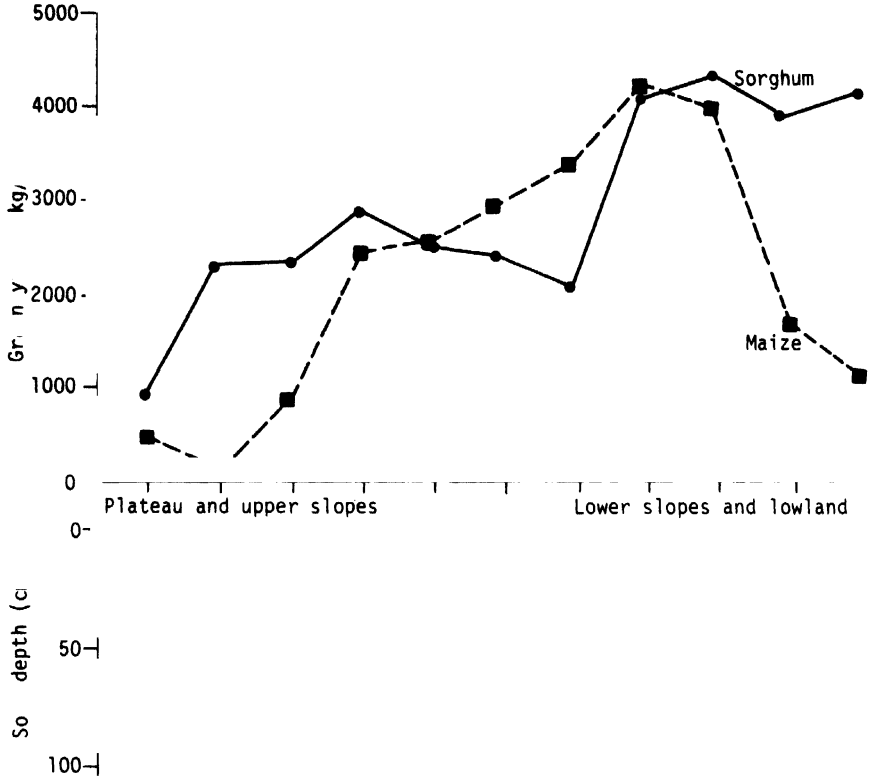

Fig. 4. Adaptation of maize and sorghum to different land types of the toposequence at Kamboinse.

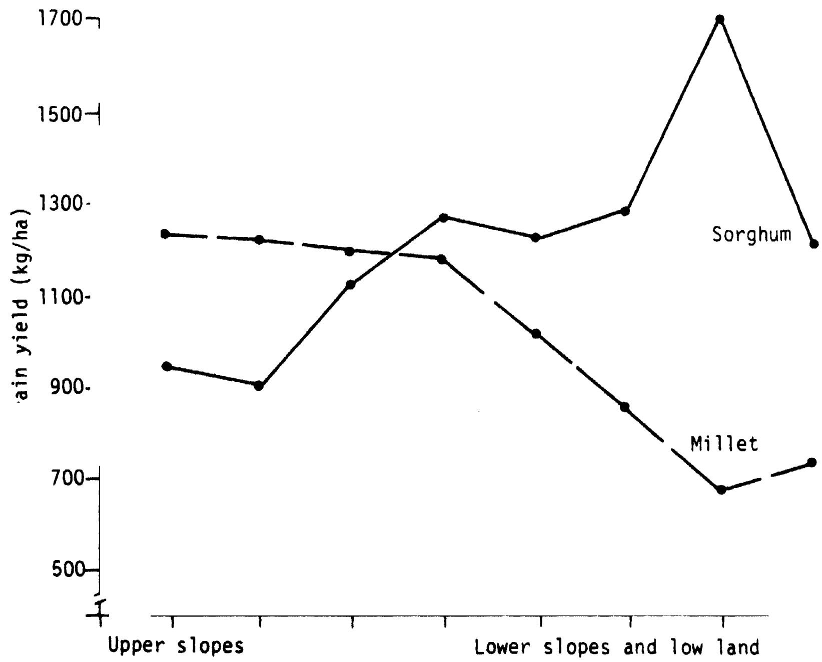

Fig. 5. Adaptation of sorghum and pearl millet to different land types of the toposequence at Kamboinse.

rate of 100 kg 14:23:15 NPK/ha followed by a side-dressing of 65 kg urea/ha at the time of the second weeding (usually about 5 weeks after planting).

RESULTS

Response of the major local cereal crops (millet, sorghum, and maize) to different toposequence positions

The exploratory trials conducted in 1977 and 1978 demonstrated that millet outyields sorghum, and sorghum outyields maize, on the relatively dry upland soils. However, on the deep, well-drained soils of the lower slopes this trend is reversed with maize being the most productive crop, although a few days of waterlogging may cause crop failures of millet and maize, leaving sorghum as a more reliable crop for the lowlands (Figs. 4 and 5). Waterlogging for extended periods, or during the very early growth stages, will seriously damage all crops.

Some of the risks of crop failure in a semiarid environment can be reduced by using the above crop adaptation pattern. In addition, however, the timing of crop sowing on different land types becomes an important strategy to avoid yield losses due to early season droughts on uplands and to mid-season floods on lowlands.

Interaction effects between date of sowing and toposequence position for the major local cereal crops

Most of the local millet and white sorghum cultivars grown in the North Sudanian zone are photosensitive types, which flower towards the end of the rainy season in September or October, irrespective of their planting date (Curtis, 1968; Bunting and Curtis, 1970). As a result, however, these local varieties respond negatively when planted after a critical date, which may vary from 30 May for sorghum in Northern Nigeria (Andrews, 1973) to the last week of June for sorghum, or mid-June for millet, grown in Central Upper Volta (ICRISAT, 1980).

Given the uncertain timing of the start of the rains, the practical advantange of these crops and their major cultivars is the extended period (some 6 weeks) over which sowing is possible, as well as their adaptation to different land types. Moreover, the problem of grain mould and pollen wash for photosensitive sorghum and millet cultivars is relatively minor because flowering coincides with the end of the rains. In this respect, the early maturing, non-photosensitive maize, complements the characteristics of the prevailing sorghums and millets.

The data from the 1979 experiments in Kamboinse and Baramandougou, summarized in Table 4, and further clarified in Fig. 6, clearly show the interactions between sowing dates and land types for the three cereal crops. Of

TABLE 4

Crop responses (grain yield and days to 50% flowering) to date of sowing and land type at Kamboinse and Baramdougou

	Kamboinse						Baramandougou	
	Local millet		Local sorghum		Maize		Local millet	Local sorghum
	Grain yield (kg/ha)	Days to 50% flowering	Grain yield (kg/ha)	Days to 50% flowering	Grain yield (kg/ha)	Days to 50% flowering	Grain yield (kg/ha)	Grain yield (kg/ha)
Date of sowing (D)	N.S.	***	N.S.	***	***	N.S.	***	***
early June	1510	104	1130	106	1500	50	—	—
late June	1450	86	1320	81	2580	49	1750	1740
mid July	—	—	—	—	—	—	1855	2010
late July	—	—	—	—	—	—	1340	1085
s.e.	140	0.3	91	0.8	155	0.7	69	69
Landtype (L)	N.S.	**	***	N.S.	***	***	***	***
uplands (gravelly)	1560	95	1200	94	1435	55	—	—
upper slopes	1630	97	1540	94	1685	49	1740	755
lower slopes	1355	94	1535[a]	93	2430	47	2010	1310
lowland (temporarily inundated)	1370	96	630[a]	94	2610	47	1084	2885
s.e.	199	0.5	129	1.2	220	1.0	167	167
Interactions								
D × L	N.S.	*	N.S.	N.S.	N.S.	**	***	***
C.V. (%)	32.9	1.2	25.7	3.0	30.5	5.9	27.8	27.8

[a] Severe aphid attack.

N.S. = non significant. ***, Significant F test at 1% level; **, significant F test at 5% level; *, significant F test at 10% level.

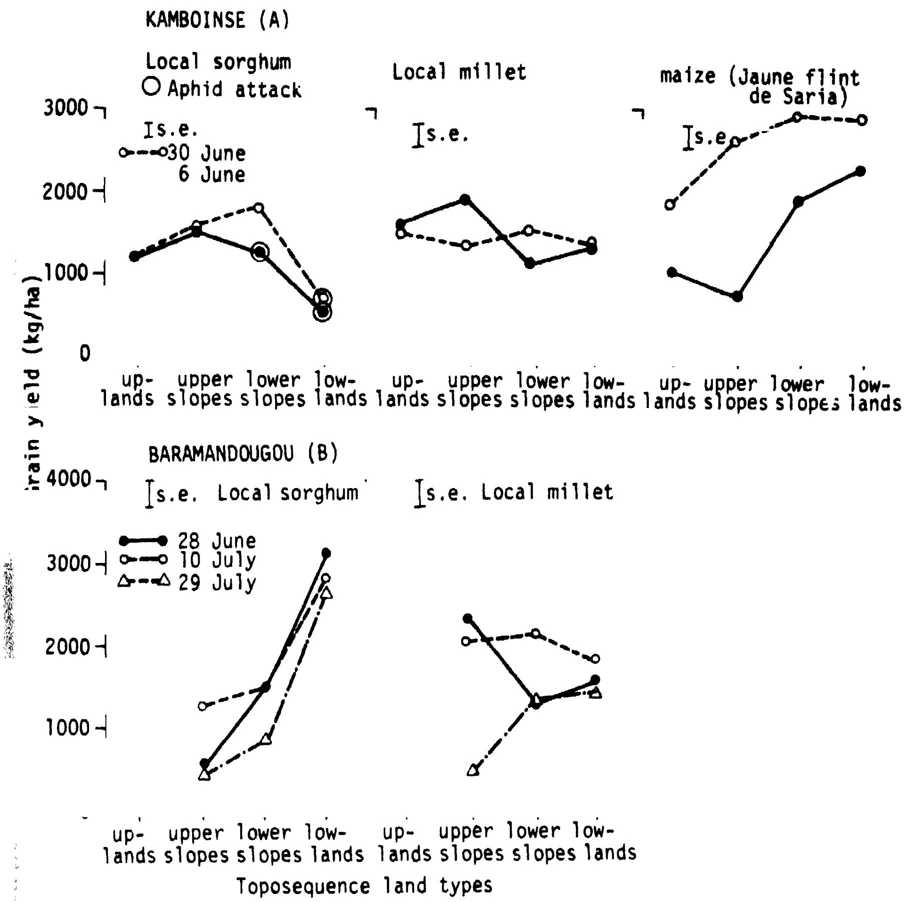

Fig. 6. Grain yield responses of the three major, local cereal crops to date of sowing and toposequence land types at Kamboinse, Upper Volta (A) and Baramandougou, Mali (B).

these crops, millet is best adapted to early planting on upland and upper slope soils, where it outyields both sorghum and maize in Kamboinse. A simimlar, even more significant response was recorded for the upper slope situation at Baramandougou. For this latter location, a combined statistical analysis showed that the major effects of sowing date and land type and also the interaction effects of crop X land type and crop X sowing date X land type were highly significant (Table 5 and Fig. 6B).

As in 1977, sorghum and maize showed highly significant responses to land types, with maize outyielding the other two crops on the lowlands and lower slopes for both early and late June planting. Satisfactory yields of maize were also obtained from the drought-prone uplands and upper slopes at Kamboinse, provided sowing was delayed to late June, when the rains became more regular than during the previous weeks.

Because of an unusual, severe, aphid attack on the two lowest land types at Kamboinse, local sorghum did not respond to land type as in previous years and as at Baramandougou. Furthermore, the data in Table 4 clearly demonstrate the photosensitive nature of sorghum and millet and non-photosensitivity of maize. The maturity of sorghum and millet appears little af-

TABLE 5

Crop response for three sorghum cultivars to dates of sowing and land types (1980 experiment)

	Grain yield (kg/ha)	Number of days to 50% flowering	Plant height (cm)
Sorghum cultivars (V)	***	***	***
Local	1875	81	403
940 S	2350	80	213
38-3	1630	76	216
s.e.	147	0.6	5.3
Dates of sowing (D)	***	***	***
14th June	2415	84	281
25th June	2060	80	286
10th July	1375	72	264
s.e.	147	0.6	5.3
Landtypes (L)	***	N.S.	***
Uplands (gravelly)	1995	79	287
Upper slopes	1515	79	263
Lower slopes	2215	80	275
Lowlands (temporarily inundated)	2080	78	283
s.e.	170	0.7	6.1
Interactions			
V × D	N.S.	***	***
V × L	**	*	N.S.
D × L	*	N.S.	N.S.
V × D × L	N.S.	N.S.	N.S.
C.V. (%)	31.9	3.2	8.1

N.S. = non significant.
***, Significant F test at 1% level; **, significant F test at 5% level; * significant F test at 10% level.

fected by land type, whereas for maize, flowering was significantly delayed under the moisture stress conditions of the upland and upper slope soils.

Interaction effects between date of sowing and toposequence land type for several introduced sorghum cultivars

This section will describe the results of two experiments. In the 1980 trial three contrasting sorghum cultivars (photosensitive local; slightly photosensitive 940S, and non-photosensitive 38-3) were sown at three dates and on four toposequence positions. A second trial was used to compare the local sorghum with the slightly photosensitive E 35-1 and with the non-photosensitive VS 702, which have maturity cycles of approximately 120 and

105 days respectively. Seeds were sown at two dates and on four land types during the 1979 season.

The results for the 1980 trial are summarized in Table 5. All the major effects on grain yield were highly significant ($P<0.01$), in addition to the cultivar × land type (Fig. 7A) and sowing date × land type (Fig. 7B) interactions (significant at $P<0.05$ and $P<0.1$ respectively). The interaction between sowing date and land type stresses the importance of timely (i.e. relatively early) sowing on drought-prone upland areas and flood-prone lowlands, whereas sowing date is less critical on the deep, relatively moist soils of the lower slopes.

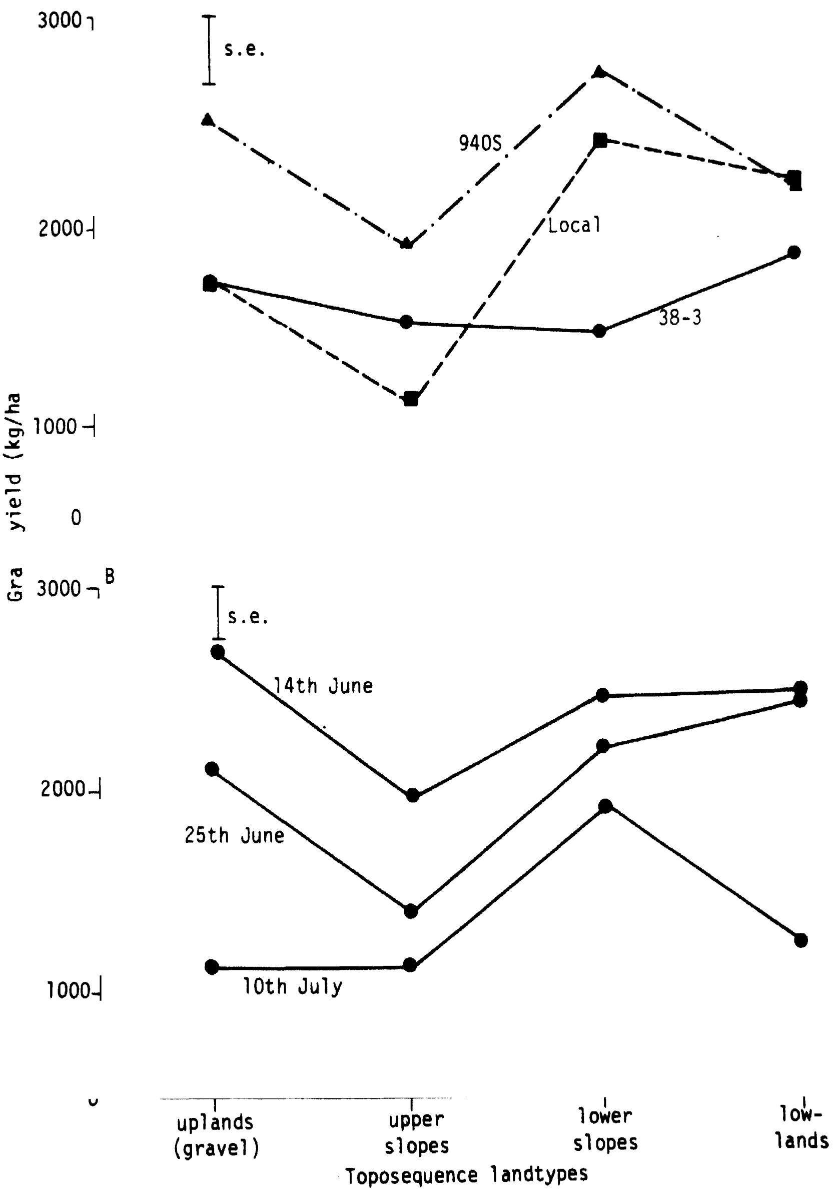

Fig. 7. Grain yield responses of three sorghum cultivars as influenced by toposequence land types (A); and sorghum yield responses to landtypes for different sowing dates (B) (1980 experiment).

TABLE 5

Crop response for three sorghum cultivars to dates of sowing and land types (1980 experiment)

	Grain yield (kg/ha)	Number of days to 50% flowering	Plant height (cm)
Sorghum cultivars (V)	***	***	***
Local	1875	81	403
940 S	2350	80	213
38-3	1630	76	216
s.e.	147	0.6	5.3
Dates of sowing (D)	***	***	***
14th June	2415	84	281
25th June	2060	80	286
10th July	1375	72	264
s.e.	147	0.6	5.3
Landtypes (L)	***	N.S.	***
Uplands (gravelly)	1995	79	287
Upper slopes	1515	79	263
Lower slopes	2215	80	275
Lowlands (temporarily inundated)	2080	78	283
s.e.	170	0.7	6.1
Interactions			
V × D	N.S.	***	***
V × L	**	*	N.S.
D × L	*	N.S.	N.S.
V × D × L	N.S.	N.S.	N.S.
C.V. (%)	31.9	3.2	8.1

N.S. = non significant.
***, Significant F test at 1% level; **, significant F test at 5% level; * significant F test at 10% level.

fected by land type, whereas for maize, flowering was significantly delayed under the moisture stress conditions of the upland and upper slope soils.

Interaction effects between date of sowing and toposequence land type for several introduced sorghum cultivars

This section will describe the results of two experiments. In the 1980 trial three contrasting sorghum cultivars (photosensitive local; slightly photosensitive 940S, and non-photosensitive 38-3) were sown at three dates and on four toposequence positions. A second trial was used to compare the local sorghum with the slightly photosensitive E 35-1 and with the non-photosensitive VS 702, which have maturity cycles of approximately 120 and

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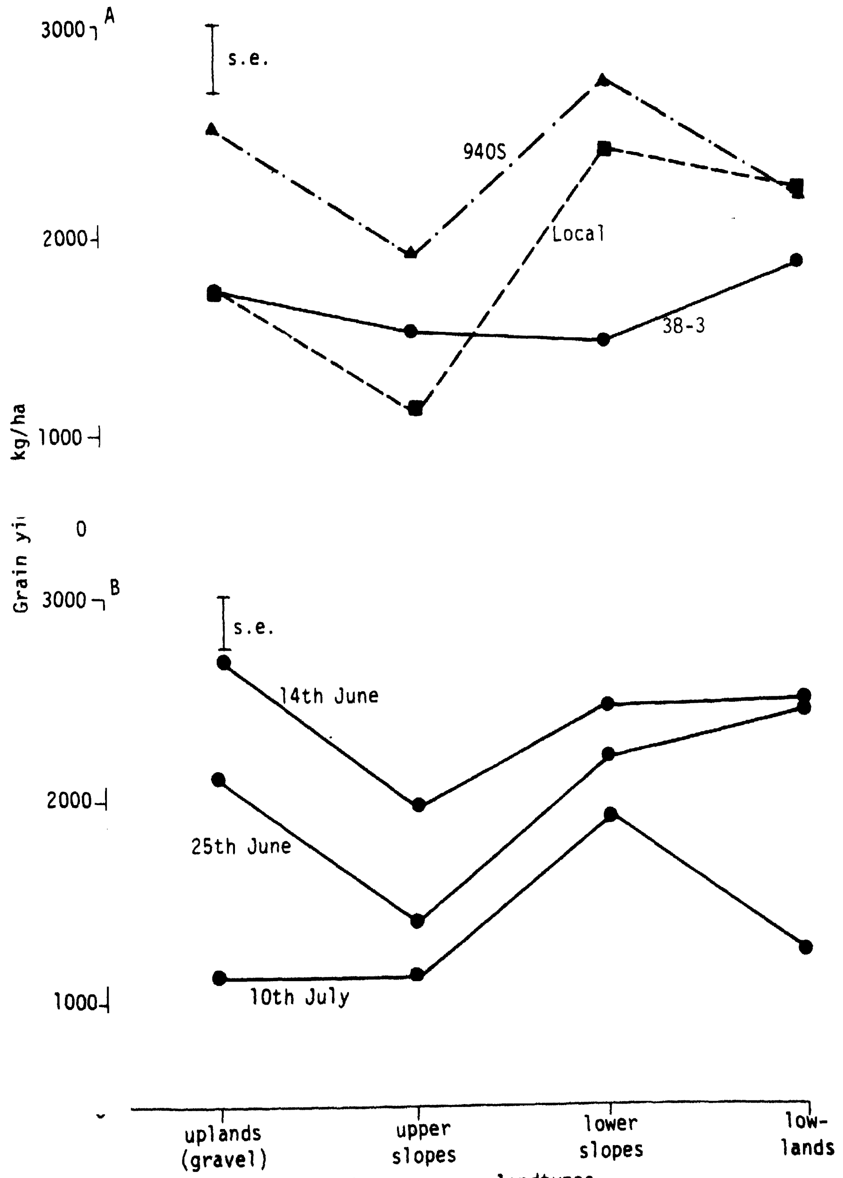

Fig. 7. Grain yield responses of three sorghum cultivars as influenced by toposequence land types (A); and sorghum yield responses to landtypes for different sowing dates (B) (1980 experiment).

Of the three sorghum cultivars, 940S outyielded the others at all three sowing dates (Fig. 8), but also on the three highest land types (Fig. 7A). Particularly, its adaptation to upland soil conditions was better than for the local or 38-3, while, due to its tillering ability, it was able to respond more readily to improved soil conditions on the lower slopes than could a non-tillering material such as 38-3.

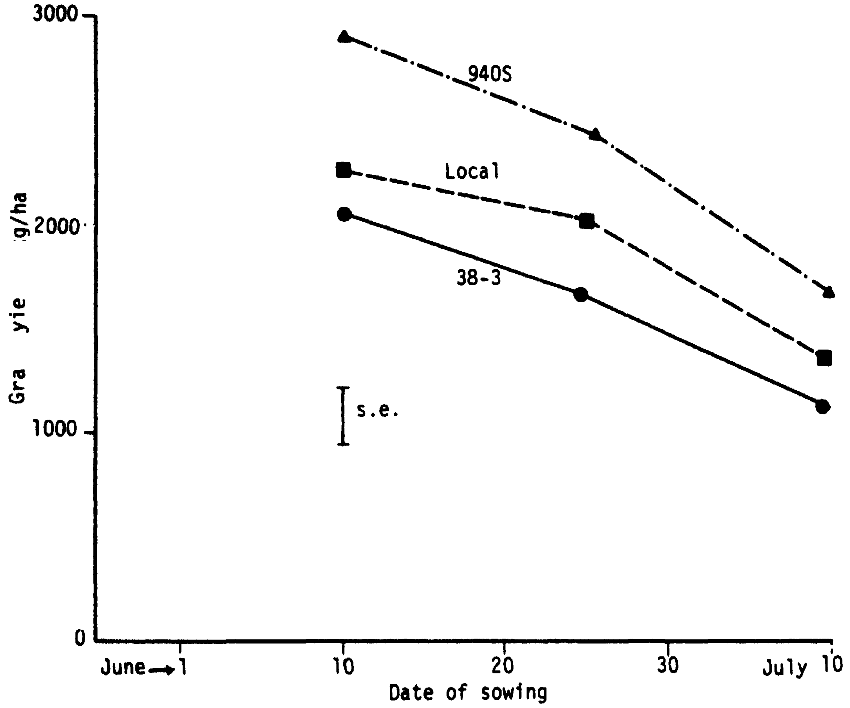

Fig. 8. Grain yield responses of three sorghum cultivars to different dates of sowing.

Other important characteristics which contribute to sorghum adaptation to land types are its maturity cycle and its degree of photosensitivity. As schematically indicated in Fig. 9, the desired sowing period becomes exceedingly short (10 days) for non-photosensitive cultivars such as 38-3 to avoid the major end-of-season hazards, which are moisture stress, grain mould and midge attack. In these respects, the photosensitive local cultivar offers the greatest flexibility at sowing and the least risk at harvest, whereas 940S takes an intermediate position.

The data on days to 50% flowering and plant height in Table 5 confirmed that for the photosensitive materials (local and 940S) the vegetative growth period, and consequently plant height, increased the earlier the crop is sown, whereas for the non-photosensitive material (38-3) these characteristics are relatively constant. The significant ($P < 0.1$) interaction cultivar × land type for the days to flowering originated from a delay in flowering of 38-3 on the uplands (i.e., under moisture stress conditions), which did not occur for the other two cultivars.

Grain yields of all three cultivars decreased with later sowing dates,

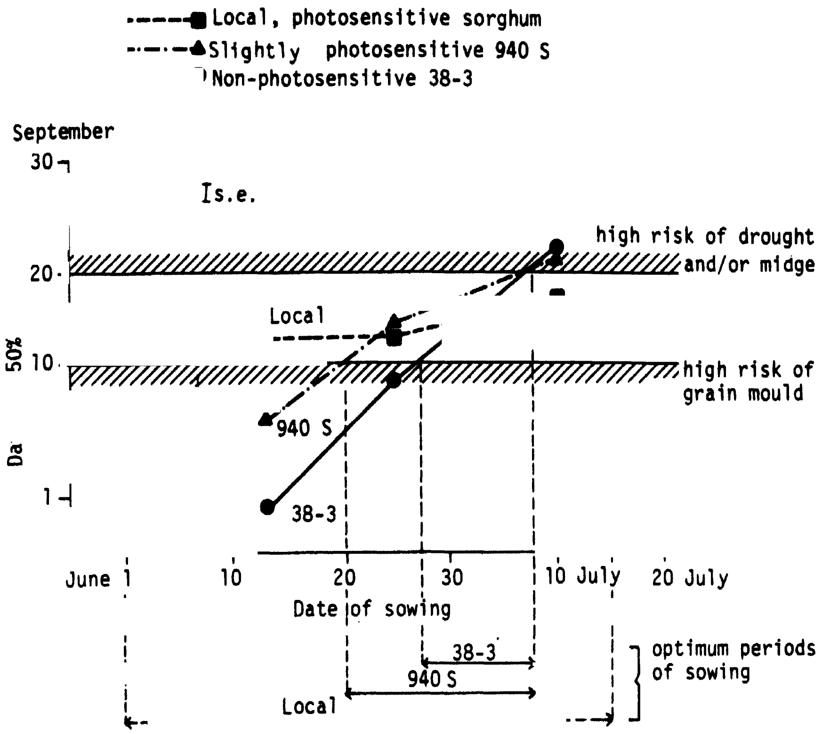

Fig. 9. Relationship between the dates of sowing and the corresponding dates of 50% flowering for three contrasting sorghum cultivars grown at Kamboinse (Upper Volta); implications of end of season drought, grain mould and midge risks for the optimum sowing period.

though the most drastic reduction occurred between 25 June and 10 July (Fig. 8). In the second (1979) trial, however, the early-maturing non-photosensitive VS 702 was able to maintain its mean yield even when sown on 14 July (Table 6). As shown in Fig. 10, this result was mainly caused by good yields from lower slopes, whereas on the uplands and upper slopes delayed sowing caused distinct yield reduction for both VS 702 and E 35-1,

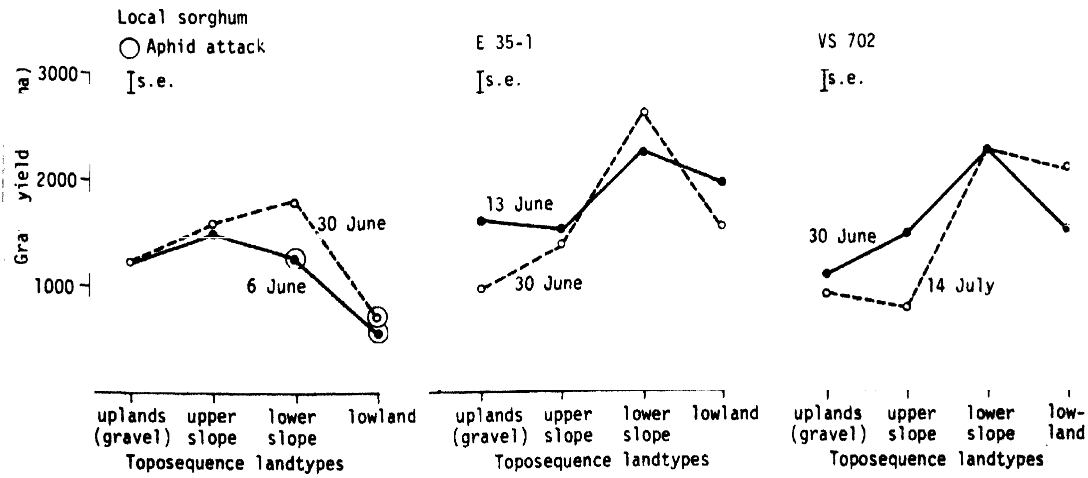

Fig. 10. Grain yield responses of three sorghum cultivars as influenced by toposequence land type and sowing date (1979 experiment).

TABLE 6

Crop response for three sorghum cultivars to date of sowing and landtype at Kamboinse (1979 experiments)

	Local			E 35-1			VS 702		
	Grain yield (kg/ha)	Days to 50% flowering	Grain mould (%)	Grain yield (kg/ha)	Days to 50% flowering	Grain mould (%)	Grain yield (kg/ha)	Days to 50% flowering	Grain mould (%)
Date of sowing (D)	N.S.	***	N.S.	N.S.	***	***	N.S.	***	N.S.
June 6	1120	106	15.2	—	—	—	—	—	—
June 13	—	—	—	1840	92	31.2	—	—	—
June 30	1260	81	14.7	1625	84	17.5	1565	72	32.7
July 14	—	—	—	—	—	—	1505	68	32.7
s.e.	91	0.8	3.3	91	0.7	2.4	94	0.8	2.5
Land type (L)	***	N.S.	**	***	***	**	***	***	*
Upland (gravelly)	1200	94	4.4	1275	93	14.0	980	74	26.3
Upper slope	1540	94	7.7	1450	93	22.7	1100	72	28.3
Lower slope	1525	93	23.0	2450	84	28.7	2255	67	36.0
Lowlands (temporarily inundated)	630	94	24.7	1760	83	32.0	1800	67	40.0
s.e.	129	1.2	4.6	128	1.0	3.5	133	1.2	3.6
Interactions									
D × L	N.S.	N.S.	N.S.	*	**	N.S.	**	N.S.	N.S.
s.e.	182	1.6	6.5	181	1.4	4.9	188	1.7	5.1
C.V. (%)	25.7	3.0	75.9	18.1	2.8	34.7	21.2	4.1	27.0

N.S. = non significant.
***, Significant *F* test at 1% level; **, significant *F* test at 5% level; *, significant *F* test at 10% level.

because of moisture stress at the flowering and grain filling stages. Consequently, relatively early planting gave the least variable yield responses to land types. However, since the date of flowering of E 35-1 and VS 702 is significantly delayed under moisture stress in the upland situations (as was the case with the cultivar 38-3 in the 1980 trial), the optimum sowing dates for each cultivar will vary among land types (Table 7). Thus, on drought-prone uplands, the sowing date for these materials should be advanced to avoid the end of season moisture stress, whereas on the moist lower slopes, it should be delayed to avoid major grain mould problems (Table 6). The impact of land type on the actual date of flowering was least for the local cultivar (Table 7), whereas only minor effects were recorded for 940 S.

TABLE 7

Effect of soil type and date of sowing on the actual date of 50% flowering for three contrasting sorghum cultivars (1979 experiment)

Cultivar:	Kamboinse local		E 35-1		VS 702	
Soil:	shallow upper slope	deep lower slope	shallow upper slope	deep lower slope	shallow upper slope	deep lower slope
Sowing date	Dates of 50% flowering					
June 6	Sept 20	Sept 21	—	—	—	—
June 13	—	—	Sept 18	Sept 9[a]	—	—
June 30	Sept 20	Sept 17	Sept 26[b]	Sept 19	Sept 15	Sept 4[a]
July 14	—	—	—	—	Sept 23[b]	Sept 17

[a] Yields around 2000 kg/ha but grain seriously moulded.
[b] Yields reduced due to moisture stress.

DISCUSSION AND CONCLUSIONS

Much of the subsistence agriculture in the West African savanna is based on manual labour, without the use of animal traction, mechanical equipment, fertilizers and pesticides, which are too costly and/or unavailable. Therefore, farmers have traditionally spread out the large early season labour requirements for sowing and weeding, as well as the risks of crop failure due to an unreliable rainfall (Norman, 1974). This has been achieved by using photosensitive cultivars which provide flexibility at sowing time, and by adapting crops and cropping systems to major land types. However, with increasing demands for food, and in years when the onset of the rains is delayed till late June, these traditional systems come under stress. As a result, large areas are sown annually with photosensitive local cultivars long after the optimum sowing period has passed. The present studies were conducted against this background.

Firstly, the data on crop adaptation to different land types in the toposequence and to different sowing dates have provided a scientific basis for the cropping patterns commonly used by farmers in the West African savanna region. Secondly, the model of crop adaptation to land types forms a useful basis for the orientation of crop improvement, and farming systems research, to develop more productive and stable, improved technologies.

A major implication of the large diversity in production environments is the need for crop improvement programmes to develop a range of improved cultivars adapted to different land types and sowing periods (see Fig. 11). Consequently, there is only a remote chance that a single high-yielding variety will be found to replace all local cultivars and the successful introduction of a standard technological package is also most unlikely. The studies on sorghum cultivar adaptation to land types and sowing dates have indicated several plant characteristics of particular relevance to improved systems.

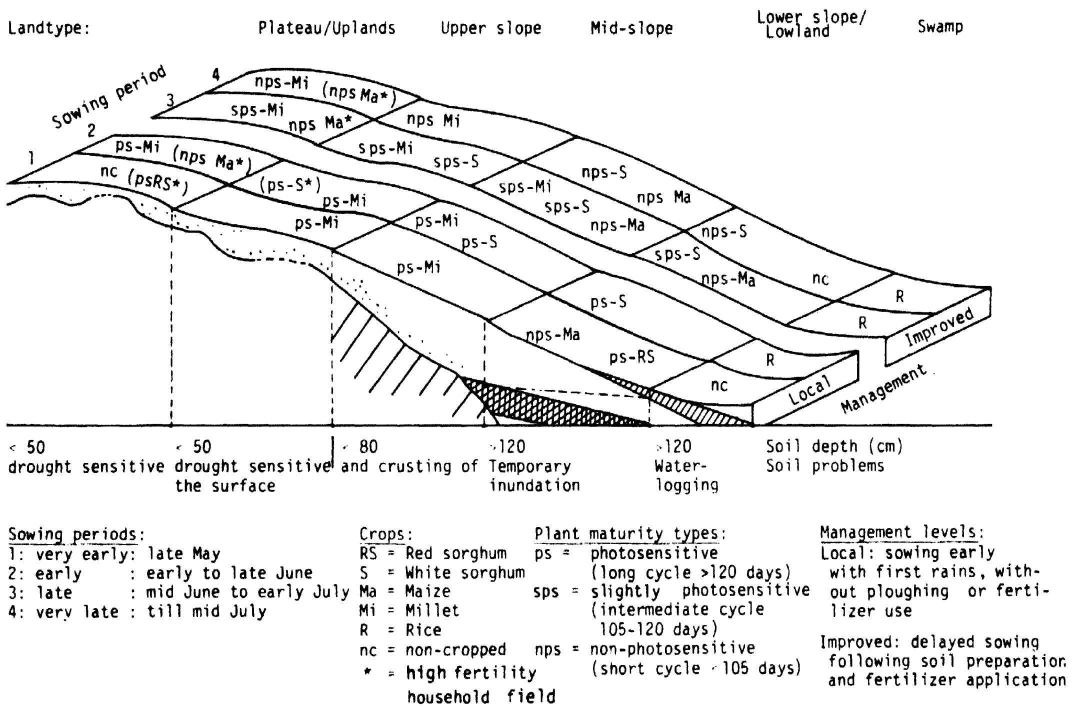

Fig. 11. Schematic presentation of relationships between crops, sowing dates and land types for a toposequence in the 650—800 mm rainfall zone of Upper Volta (for soil description see Fig. 1).

(A) The slightly photosensitive sorghum cultivar gave the highest and most stable yields on the various land types, whereas the strongly photosensitive cultivar provided the greatest stability at the different sowing dates. In spite of their high yields under optimum conditions, the non-photosensitive cultivars like 38-3 and VS 702 provided the least flexibility in terms of sowing period, and consequently involved a greater risk than photosensitive materials. Nevertheless, some of these materials may fill a particular 'niche' in the

·sent farming system, especially those with a short maturity cycle, though ·y will always demand relatively fertile and deep soils.

(B) Flowering was delayed in non-photosensitive cultivars, including E 35- when they were exposed to moisture stress in the uplands. Since the ›wering of sorghum should coincide with the end of the rains (to avoid ·in mould problems), any subsequent delay in flowering is likely to cause ·ld losses. Stability in date of flowering across different land types and wing dates as shown by the Kamboinse local and 940 S cultivars therefore ›uld appear a major asset to overcome the severe moisture and fertility resses to be expected when improved cultivars are transferred from the re- arch establishment to the farmers' fields.

(C) Among the sorghum cultivars, the local and 940 S responded best to ›e more favorable soil conditions of the lower slopes. This yield response as partly attributed to the tillering ability of these materials. In the context f local agriculture, which generally uses low plant densities (because of and planting and a frequent loss of plants due to early droughts), this llering ability may therefore be of considerable significance.

From an agricultural management viewpoint the data indicate that with nproved soil preparation including the use of fertilizers and tied ridges, ·veral introduced sorghum cultivars when sown in the second half of June, an outyield millet on upland and upper slope fields. As a consequence, arious shifts in the traditional cropping patterns would become possible as ndicated in Fig. 11 for the North Sudanian zone. However, in years with egular early rains (e.g., starting in May) sowing should not be postponed ieliberately to suit an improved cultivar with a short maturity cycle, but nstead another photosensitive cultivar, adapted to early planting, should be ised. Certainly in the Sudanian zone, where subsequent rains are unpredict- ·ble, where runoff and erosion are severe and labour constraints (for sowing nd weeding) are common, any delay in establishing a crop, may have very ·erious repercussions later on in the season.

The environmental diversity common to large parts of the West African ·emiarid tropics and the implications for developing, testing and introducing new, well-adapted, sorghum cultivars have been examined in this paper. It is expected that the present breeding programmes for sorghum and millet, which emphasize the selection of materials derived from crosses, between local cultivars and promising introductions, will yield the essential wide range of adapted, improved, cultivars to fit both the traditional and improved management systems.

Given the unpredictable rainfall and large variations in soils, even improved management systems probably need to rely on intercropping to improve the production/ha, and to maintain yield stability. This rationale for intercropping is provided by the cross-over of the yield curves for sorghum, millet, and maize in response to the toposequence land types (Figs. 4 and 5). Evidence was obtained that the cross-over points may shift considerably in direct reponse to the rainfall conditions, which may vary greatly from year to year. A later article will consider the possibilities for various cropping systems, based on local and introduced sorghums, and the adaptation of such systems to the major toposequence land types.

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