UNIVERSITY OF CALIFORNIA
RIVERSIDE

Stability of Dryland Production of Cowpeas (Vigna unsuiculata (L.) Walp.) with Varietal Intercrops

A Thesis submitted in partial satisfaction
of the requirements for the degree of

Master of Science

in

Plant Science

by

Samba Thiaw

December, 1990

Thesis Committee:

Professor Anthony E. Hall, Chairman

Professor Jodie S. Holt

Professor Giles J. Waines

The thesis of Samba Thiaw is approved:

Jodie S. Holt

J. Giles Waines

Anthony E. Hall
Committee Chairman

University of California, Riverside
December, 1990

ABSTRACT OF THE THESIS

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Samba Thiaw
Master of Science, Graduate Program in Plant science
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Low and variable yields constrain grain production under rainfed conditions in semiarid zones. These problems are particularly acute in northern Senegal where grain production is limited by low and variable rainfall. This study was conducted to determine whether varietal intercrops of cowpea are better adapted to semiarid climates and infertile soils than sole crops of cowpea. The same experiment was conducted over two years in three locations in northern Senegal which have contrasting rainfall and soil fertility. The locations are representative of the major cowpea production zones of Senegal. Two varietal intercrops and six cultivars were grown in a randomized complete block split plot design with 4 replications. The varietal intercrops consisted of alternating rows of a

medium cycle spreading cultivar (58-57) and an early erect cultivar (Bambey 21 or CB5). The six cultivars grown as sole crops included the three cultivars used in the intercrop and three others with spreading (N'diambour and Mougne) or semierect (Tvx 3236) growth habit that are well adapted to northern Senegal. The split plots consisted of application of fertilizer (150 kg/ha of 6:20:10, N: P_2O_5:K_2O) and a control where no fertilizer was applied. Grain and hay yield responded significantly to fertilizer application at the two drier locations, Thilmakha and Louga, but not at Bambey which according to soil analysis had higher levels of nitrogen and phosphorus. There were no genotype x fertilizer interactions. Cultivar and intercrop comparisons were based on mean yields across the soil fertility treatments. The varietal intercrops were more effective at Thilmakha and Louga than the sole crops. In these drier and less fertile locations the varietal intercrops had the highest mean yields of grain and hay, the highest land-use efficiency (LERs of 1.42 for grain and 1.50 for hay), and above average stability. In the wetter and more fertile location (Bambey), the performance of the varietal intercrop was intermediate, and the dense canopy made it difficult to harvest the grain of the two cultivars in the intercrops separately. These studies demonstrated that intercrops of early erect and medium cycle spreading cowpeas can have higher and more stable yields of grain and hay than sole crops, in conditions where drought and infertile soi.1 limit crop production.

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INTRODUCTION AND LITERATURE REVIEW

The cropping systems that are most effective in semi-arid zones must be adapted to the soil, biotic and climatic conditions. In these zones, yields are generally low and variable as a conseguence of limited and variable rainfall and other constraints.

In semiarid regions of Senegal, most farmers do not have water for irrigation and they must rely on rain to produce their food and cash crops. In the Sahelian and Sudanian zones of Senegal, the average rainfall provides sufficient moisture for a 60 to 100 day cropping season which is followed by a long dry season (Dancette and Hall, 1979). Drought often occurs at different times during the cropping season, substantially reducing crop production.

Cowpea (Vigna unsuiculata (L.) Walp.) is a warm season crop that has been grown in Senegal for thousands of years (Ng and Marechal, 1985). Formerly, it was planted in home gardens or intercropped with cereals or other crops. Spreading, late flowering types of cowpea, which were photoperiod sensitive, were mainly used. During the last thirty years, new cultivars have been developed with early and medium maturity and erect or spreading growth habit. These cultivars have different levels of drought resistance depending on the stage of plant development when the drought occurs (Hall and Patel, 1985).

Cowpea is an important crop in the northern peanut basin in Senegal due to its ability to produce food under conditions of drought and infertile soils where the other staple crops, pearl millet, sorghum and peanut have, in some years, produced virtually no food. For subsistence farmers under conditions of variable drought and other soil and biotic constraints, yield stability may be more important than high yield. Cropping systems of semiarid West Africa were reviewed by Fussell and Serafini (1985) who concluded that pearl millet/cowpea intercrops could enhance and stabilize yields compared with sole crops. However, C. Dancette evaluated pearl millet/cowpea intercrops in the semiarid zone of Senegal over a five year period and concluded that sole crops were most effective in the drier zone (N'doye et al. 1984).

Presently, more than 90% of the cowpeas cultivated in the semiarid region of Senegal are grown as sole crops. Varietal intercrops, combining morphologically and phenologically contrasting cultivars of cowpea, could enhance yield stability and contribute to food requirements (Hall, 1988). In northern Senegal, farmers usually experience food shortages just before the pearl millet and traditional cowpea cultivars are ready to harvest. Cowpea cultivars with earlier maturity can provide food and cash during the traditional period of hunger, as well as greater grain yield than later maturing cultivars when the rainy season is very short. Medium maturing and spreading cultivars can produce more grain and hay than the early erect cultivars when the rainy season is of adequate duration. On-farm studies in Senegal have demonstrated that fanners like to grow both types of cowpeas: the early erect cultivars and the medium cycle spreading ones (N'diaye, 1987; Bal, 1988). Possible advantages from varietal intercrops consisting of alternating rows of these two types of cultivars may be seen from the following example. Where drought occurs early in the season, the early cultivar may senesce, but if rains resume, a late maturing cultivar grown in a varietal intercrop could compensate by spreading into the space made available by the senescence of the early cultivar.

Few studies were discovered in the literature in which the stability of varietal intercrops was evaluated. Rattunde et al. (1988) combined morphologically and phenoltogically different cultivars of groundnut as mixed intercrop and row intercrop. They found that the highest pod yields of the mixed intercrop and row intercrop failed to exceed the yield of the best sole crop at low and high densities. They concluded that future experimentation with groundnut mixtures in the tropics should focus on stabil-.ity rather than maximization of yield.

The performance of intercrops is often evaluated by use of Land Equivalency Ratio or LER. LER is the relative land area under two sole crops that would be required to produce the same yield as the intercrop (Hiebsch and McCollum, 1987). It gives a valid estimate of efficiency when both intercrop and monoculture are under the same level of management and monocultures are under optimal population levels. Nageswara et al. (1990) evaluated the performance of intercropping short and long duration groundnut genotypes in environments subjected to end-of-season-droughts. The intercrop treatments resulted in LERs of 0.93 to 1.25 with a mean of 1.1 for pod yield and 0.99 to 1.15 with a mean of 1.1 for total biomass at the end of the season. They concluded that growing groundnut genotypes with different season length reguirements as an intercrop is a better solution to variable season length tlhan simply spreading the risk by growing a range of genotypes as sole crops.

Preliminary studies in Senegal by Diouf (1986) and Diagne (1986) also demonstrated that varietal intercrops can be more effective than sole crops. Diagne (1986) compared varietal intercrops of cowpea consisting of alternating rows of an early erect cultivar and a medium cycle spreading cultivar with sole crops of the same cultivars. In the first year, the LER for grain yield was only slightly greater than unity (1.08). In the second year, the varietal intercrop made much more efficient use of the land than the sole crop with an LER for grain of 1.41 (Diagne, 1986). In addition, the varietal intercrop produced 20% more grain than the highest yielding sole crop and 58% more grain and 40% more hay than the average yields of the sole crops. The studies described above were all conducted at Bambey in the wetter part of the semiarid zone of Senegal. It is particularly important to evaluate varietal intercrops over a range of drier environments which exhibit more extreme and more variable levels of drought.

Hiebsch and McCollum (1987) conducted an extensive review of the literature on intercropping. They concluded that large values of LER occurred when components of the intercrop had large differences in time of maturity and when leguminous crops were grown in soil with low supplies of nitrogen (Hiebsch and McCollum, 1987). These conclusions would apply when a cowpea varietal intercrop of early and late maturing cultivars is grown in the infertile soils in the drier part of the semiarid zones of Senegal. Fertilizer response studies have demonstrated that in the northern peanut basin, deficiencies of nitrogen and phosphate limit cowpea production,, whereas in the central peanut basin deficiencies of potassium are also present (Nicou and Poulain, 1969). Hiebsch and McCollum (1987) also proposed a method which is more effective than LER to evaluate the biological efficiency of intercrops, the Area x Time Equivalency Ratio (ATER). ATER differs from LER in that it adjusts for any differences in occupancy duration of the land by the components of the intercrop. Yield response to variation in environment due to years and locations is also an important criterion to assess the adaptation of cropping systems or cultivars to semiarid environments. Long-term average yield and yield stability are important indices of adaptation (Hall et al., 1979). Several methods are available to evaluate yield stability (Blum, 1988), but they can make different predictions concerning the relative stability of the same set of cultivars (Hall et al., 1979).

A widely used method to evaluate stability consists of the regression of the yield of individual cultivars against an environmental index consisting of the mean yield of all cultivars in the tria'1 using data from different locations and years (Finlay and Wilkinson, 1963). Linear regression, as used by Eberhart and Russe1 (1966), would appear to be more appropriate than the logarithmic regression used by Finlay and Wilkinson, (1963), however, because it provides equal weighting to the different environments. The final step consists of plotting the regression coefficient against the overall mean yield of the cultivars (Finlay and Wilkinson, 1963). Cultivars with high mean yields and regression coefficients less than or close to unity would be considered to be broadly adapted to all environments experienced in the trials, whereas cultivars with very low regression coefficients would tend to be adapted to the test environments with low yield potential (Blum, 1988). Eberhart and Russe1 (1966) pointed out that the deviations from regression of individual cultivars provided an additional measure of stability, but this parameter is not a measure of general stability (Hall et al., 1979). Multiline mixtures of soybean have been compared with pure lines. In one study, certain mixtures had greater stability and higher yields than the pure lines (Schutz and Brim, 1971). The four cultivars used by Shutz and Brim (1971) had substantial differences in maturity date (29 day range), but only modest differences in morphology; they were upright and determinate. In another study, there were no significant differences in yield and regression coefficients between mixtures and pure lines (Walker and Fehr, 1978). Walker and Fehr (1978) used many pure lines but the maturity dates of the lines were within a-lO-day range and the morphologies of the lines were similar. For mixtures or intercrops to have greater stability than pure lines grown as sole crops, the component lines may have to exhibit substantial differences in morphology and phenology.

The main objective of this study was to compare the average yield, yield stability and efficiency of land use of varietal intercrops and sole crops of cowpea grown in several locations with contrasting levels of drought and soil fertility.

MATERIALS AND METHODS

During the summers of 1988 and 1989, the same experiment was conducted in three semiarid locations in Senegal West Africa with contrasting rainfall (Figure 1 and Table 1). The climate of Senegal has one rainy season lasting from two to five months. All food and cash crops are grown during this season. The three experimental sites were Bambey, Louga and Thilmakha (Figure 1). At Bambey the experiment was conducted on a deep, slightly leached, tropical ferruginous soil, called a "Dior" soil. Based on the International Soil Science Classification, this soil has 7% clay, 3% silt, 68% fine sand, 22% coarse sand, and little variation in texture in the first 2 m. The volumetric moisture content at field capacity is 16±2%. Using the United States Department of Agriculture (USDA) Soil Taxonomy, this soil is classified as a Ustipsamment (Hall and Dancette, 1978). Louga and Thilmakha are located in the northern part of the peanut basin and the soils are sandy with a low percentage of clay (3%) and a low field capacity (8%). The pH of the soils is neutral to acidic although soils at Louga and Thilmakha are more acidic than at Bambey.

Cultural oractices

Fields were chosen where pearl millet had been grown the previous year and they were plowed during the dry season in May. All trials were hand planted when the soil was

Figure 1. Central and northern peanut basin in Senegal. Experiments were conducted at Bambey, Louga, and Thilmakha.

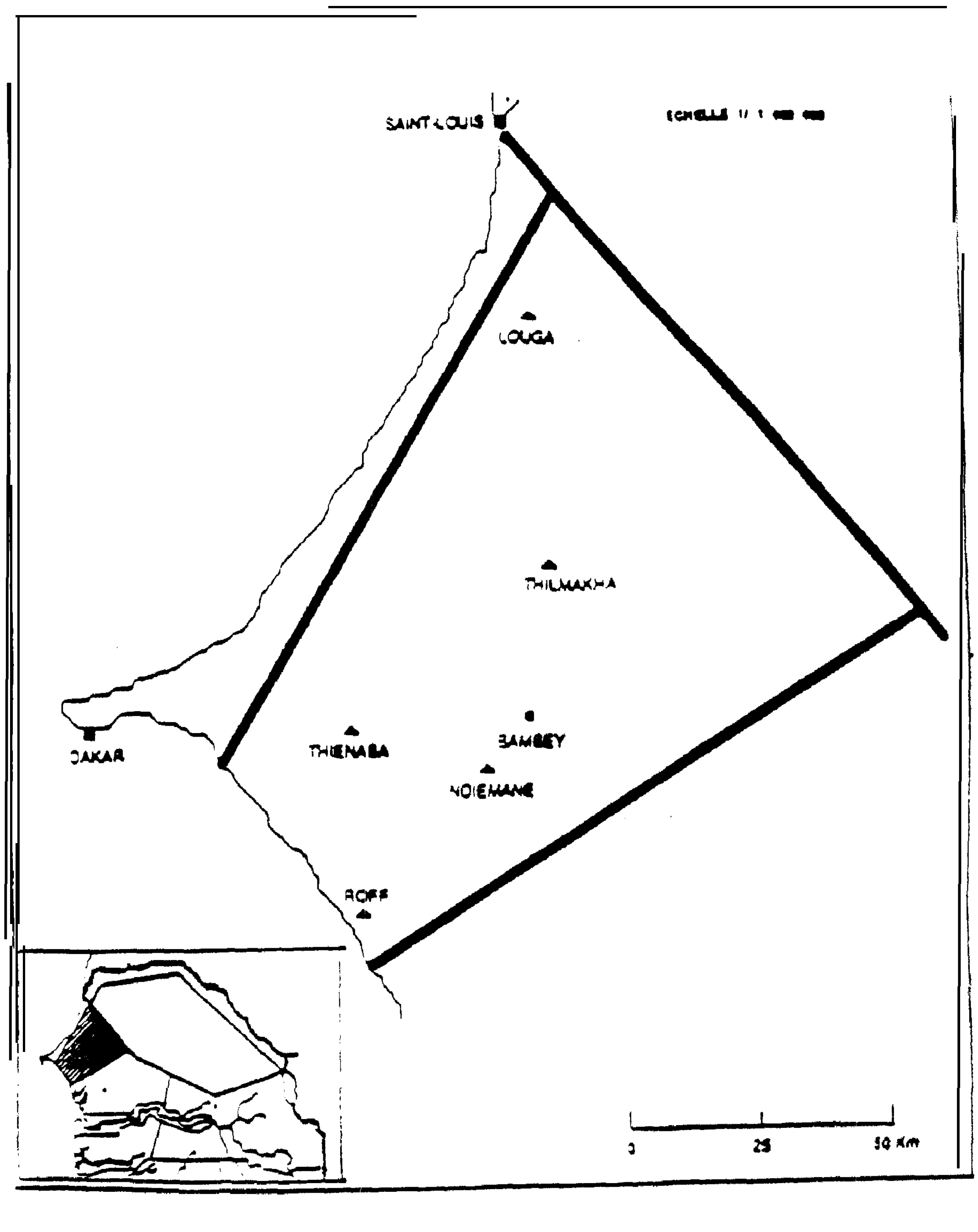

SAINT-LOUIS
LOUGA
THILMAKHA
DAKAR
THIENABA
BAMBEY
NDIEMANE
ROFF
0
25
50 Km

Table 1. Sowing and harvesting dates for cowpea and rainfall amount and duration at Bambey Louga and Thilmakha for each year.

Location	Year	Rainfall amount (mm)	Rainfall days (no.)	Dates of sowing	Dates of harvesting
Bambey	1988	6391	50	8-4-88	10-14-88
Thilmakha	1988	409	33	8-4-88	10-5-88
Louga	1988	442	32	7-30-88	10-14-88
Bambey	1989	805	42	6-28-89	9-15-89
Thilmakha	1989	550	34	7-8-89	9-20-89
Louga	1989	470	31	7-8-89	9-30-89

sufficiently wet from natural rainfall to insure germination and plant establishment (Table 1). Two seeds of six cowpea cultivars were planted per hill and hills with zero emergence were replanted o:ne week later. After seedling emergence, the hills were thinned to one plant per hill in all locations. Weeds were removed about 15 days after emergence, when the cowpea seedlings were well established. The trials were hand weeded with a hoe three times during the cropping season.

Chemical control of insects was maintained in all three locations. Hairy caterpillar (Amsacta molonevi DRC) is particularly damaging to the young seedlings and cowpea aphid (Aphis craccivora Koch) damages the meristems and tender stems. Both insects were controlled by Thimul 35 applied at the rate of 2.5L per ha (the active ingredient is endosulfan at 800 g/ha). The other major insect was the flower thrip (Meqalurothrips siostedti Trybom) which was controlled with Decis applied at the rate of 25g per ha (the active ingredient is deltamethrine at 15 g/ha).

Experimental desisn and treatments

Six cowpea cultivars (Table 2) and two varietal intercrops provided eight treatments which were planted in a randomized complete block split plot design. The eight treatments were in the main plots and two fertilizer levels were in the the sub-plots. The main plot consisted of 12 rows, each 5 m long. The distance between rows was 50

Table 2. Origin and characteristics of the cowpea cultivars used.

Cultivars	Origin	Period from sowing to 50% flowering*	Growth habit	Weight/ seed
		(days)		(mg)
58-57	Senegal	44	spreading	118
N'diambour	Senegal	44	spreading	177
Mougne	Senegal	46	spreading	129
Tvx 3236	IITA, Nigeria	45	semi-erect	106
Bambey 21	Senegal	41	erect	141
California Blackeye 5 (CB5)	USA	38	erect	176

cm for all cultivars in all locations. Within the rows the distance between hills varied from 25 cm for the erect cultivars to 50 cm for the spreading ones. A semi-erect cultivar, Tvx 3236 was sown at 50 cm within rows. The two intercrop treatments consisted of an early-erect cultivar Bambey 21 or California Blackeye No. 5 (CB5), and a medium-maturity spreading cultivar, 58-57, sown in alternate rows. The four central rows of each sub-plot were harvested at the end of the rainy season (Table 1) to determine dry weight yields of grain and hay.

Prior to applying fertilizer, soil samples were taken at Bambey, Louga, and Thillmakha in the 0-20 cm depth for analysis. The concentrations of total N, P (P_2O_5), and exchangeable K (K20) were determined. One of the split plots received fertilizer which was broadcast and incorporated at the rate of 150 kg/ha of 6-20-10 ($N:P_2O_5:K_2O$). Fully expanded, mature leaves were sampled at mid-bloom (between 35 and 45 days after sowing) from the cultivars 58-57, Mougne, Bambey 21, and CB5 in both the control and the fertilized plots. Leaf blades were ground and passed through a 20 cm-mesh screen and digested by the rapid nitric/perchloric acid method. The K and micro-nutrient (Fe, CU, Zn and Mn) contents in the leaves were determined by atomic absorption spectrophotometry. The level of P in the leaf blades was measured using the modified colorimetric method of Berg and Gardner (1978). At harvest, the number of peduncles, pods per plant and pods per peduncle were dletermined for the cultivars 58-57, Bambey 21 and CB5. Weather stations at Bambey and Louga provided data on rainfall, daily pan evaporation (US Weather Bureau Class A), and the daily maximum and minimum shelter air temperatures. At Thilmakha, only rainfall was measured.

RESULTS AND DISCUSSION

Weather conditions

There was more rain in 1989 than 1988 and Bambey received more rain over more days than Thilmakha and Louga (Table 1). Comparison of rainfall and pan evaporation indicated that the rainfall in 1988 would have supported a 70-day growing season at Elambey, but only a 60-day growing season at Louga (Figure 2). A drought occurred at Louga during the fourth ten-day interval when the cowpeas were in the early flowering stage. In 1989 there was sufficient rain to support a 90-day growing season at Bambey, but only a 70-day growing season at Louga where the sandy soil has limited ability to store water in the root zone (Figure 3). An extreme drought ocurred at Louga during the second and third ten-day intervals after sowing when the cowpea was in the late vegetative stage. The rainfall at Thilmakha (Figure 4) was more similar to the rainfall at Louga than at Bambey for both years (Figures 2 and 3), with Thilmakha receiving 33 mm less rain than Louga in 1988 and 80 mm more rain in 1989 (Table 1). The daily evaporation data at Thilmakha would have been similar to the data obtained at Louga. The daily mean pan evaporation was lnigh and dependent on the rainfall. At Bambey the mean evaporation from sowing to harvesting was 6.4 mm and 6.1 mm in 1988 and 1989, respectively, whereas at Louga it was 6.0 and 6.1 mm from sowing to harvesting for the two

Figure 2. Mean rainfall and evaporation for every ten day interval from sowing at Bambey and Louga in 1988.
ETP = Evaporation from Class A Pan.

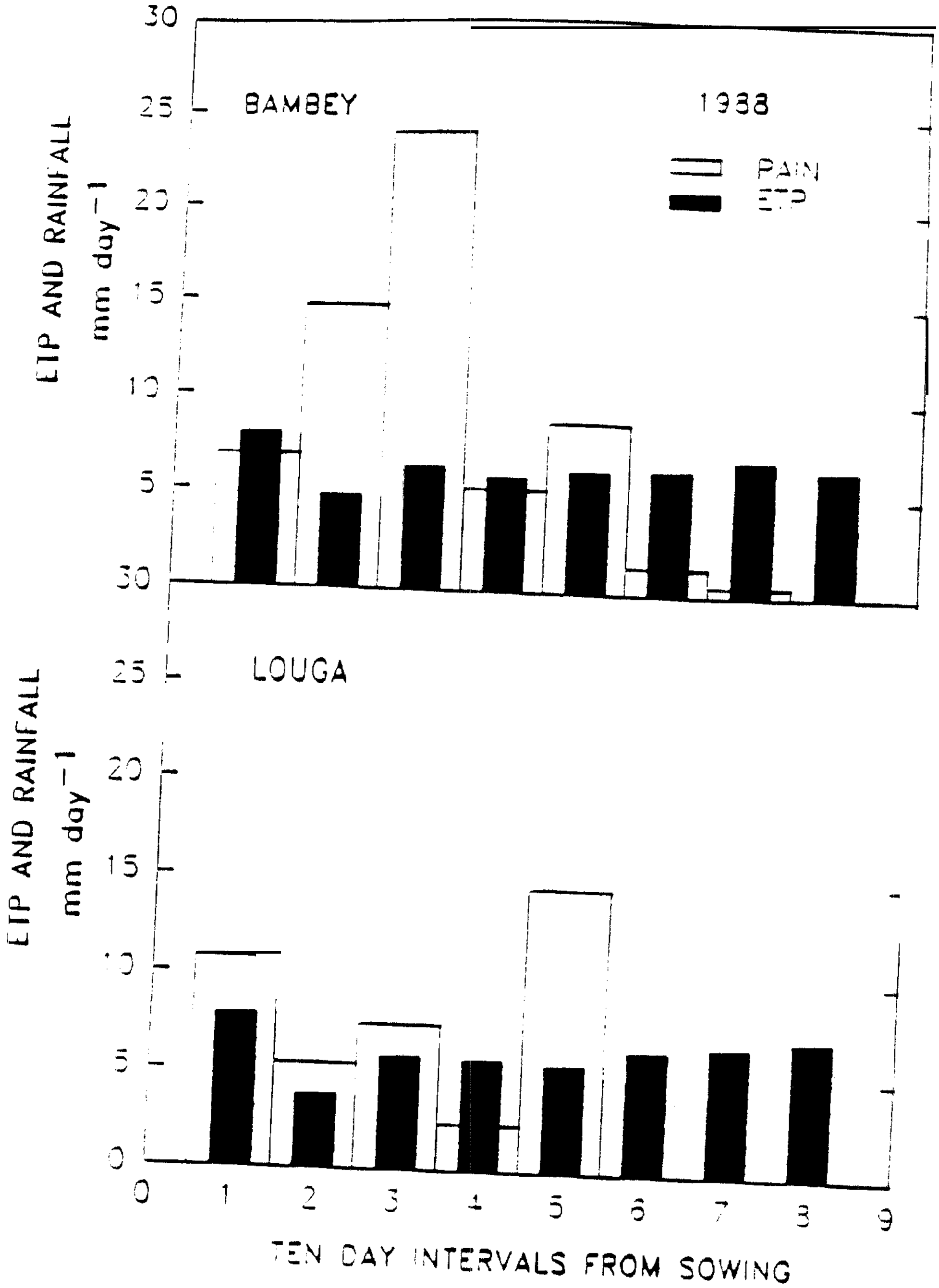

BAMBEY
1988
RAIN
ETP
LOUGA
ETP AND RAINFALL mm day⁻¹
TEN DAY INTERVALS FROM SOWING

Figure 3. Mean rainfall and evaporation for every ten day interval from sowing at Bambey and Louga in 1989.
ETP = Evaporation from Class A Pan.

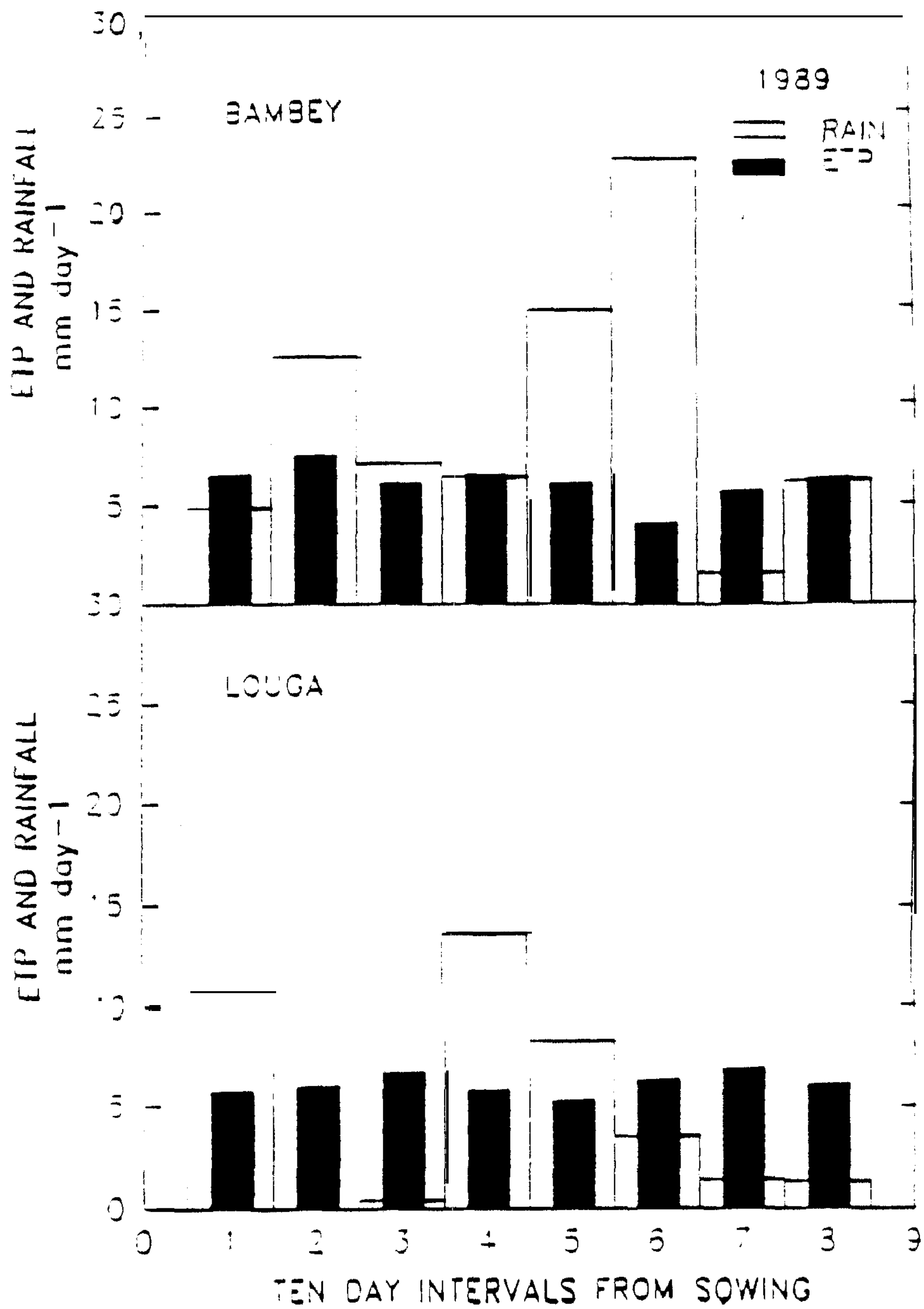
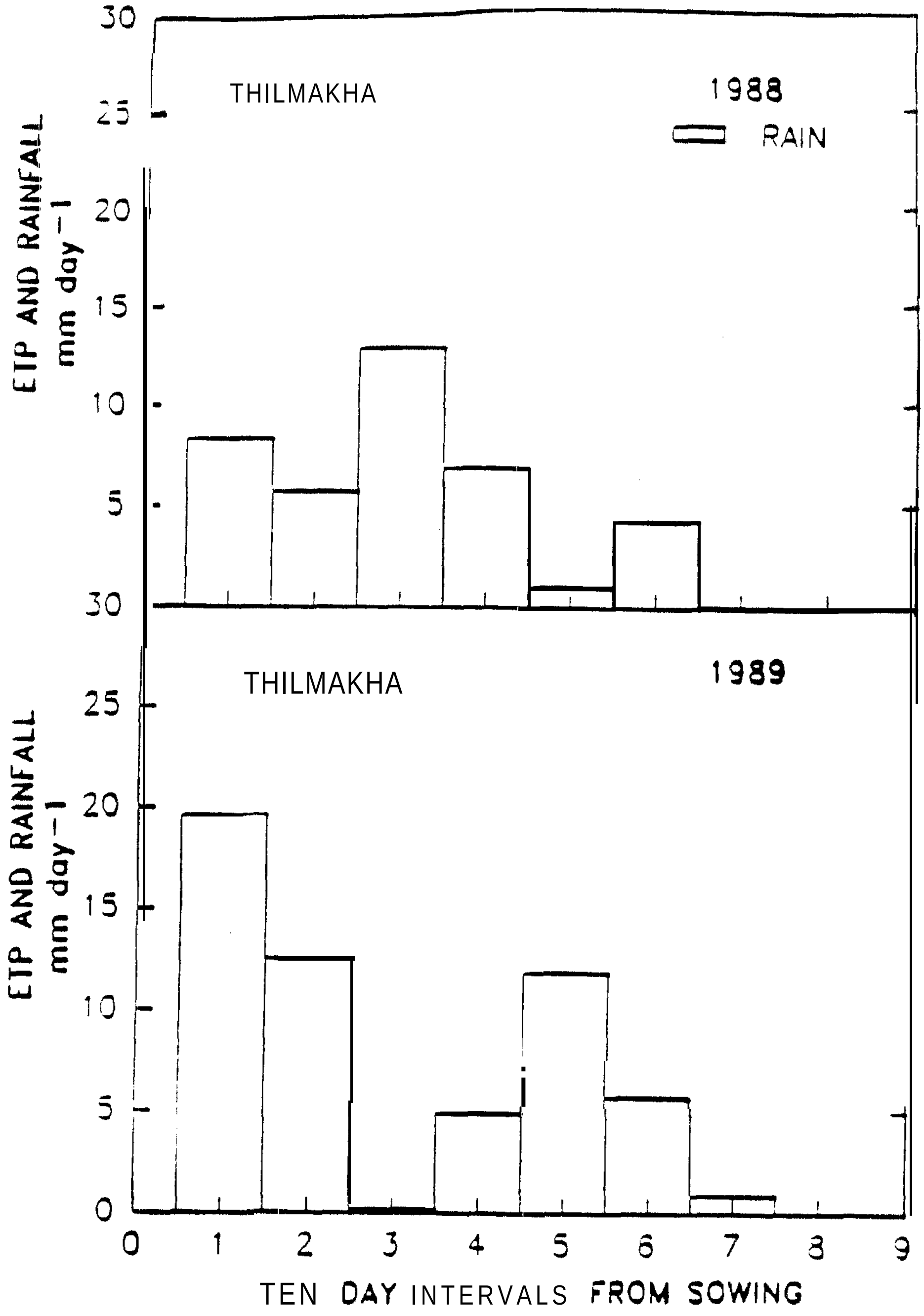

BAMBEY
1989
RAIN
ETP
LOUGA
ETP AND RAINFALL mm day-1
ETP AND RAINFALL mm day-1
TEN DAY INTERVALS FROM SOWING

Figure 4. Mean rainfall for every ten day inter-val from sowing at Thilmakha in 1988 and 1989.



THILMAKHA
1988
RAIN
THILMAKHA
1989
ETP AND RAINFALL mm day−1
ETP AND RAINFALL mm day−1
0
5
10
15
20
25
30
0
1
2
3
4
5
6
7
8
9
TEN DAY INTERVALS FROM SOWING

years. The daily maximum and minimum air temperatures averaged over a ten day period were similar in 1988 and 1989 at Bambey (Figure 5) and Louga (Figure 6) . Daily maximum and minimum air temperatures were uniformly high, averaging 33 and 24 °C, respectively, at Bambey and 34 and 24 °C, respectively, at Louga.

Response to fertilizer

Soil analysis conducted in 1989, prior to applying the fertilizer, showed that total N and P were substantially lower and more deficient at Thilmakha and Louga than at Bambey (Table 3). The level of exchangeable K was similar in the three locations. No significant differences were observed between the fertilized and the control treatments in leaf blade :mineral content, but significant differences were observed between locations in all minerals except P (Table 4). The levels of P in the leaf blades were intermediate and not significantly different between the three locations despite the higher P content in the soil at Bambey. The K level was lower at Thilmakha than at the two other locations. Among the micro-nutrients, Mn was higher at Louga and Thilmakha, possibly reflecting a lower soil pH than at Bambey (Table 4).

The fertilizer treatment resulted in significantly higher yields of grain (Table 5) and hay (Table 6) than in control plots at Thilmakha and Louga but not at Bambey. Bambey had higher soil N in the contra1 plots than did the

Figure 5. Mean maximum and minimum air temperature for every ten day interval from sowing at Bambey in 1988 and 1989.

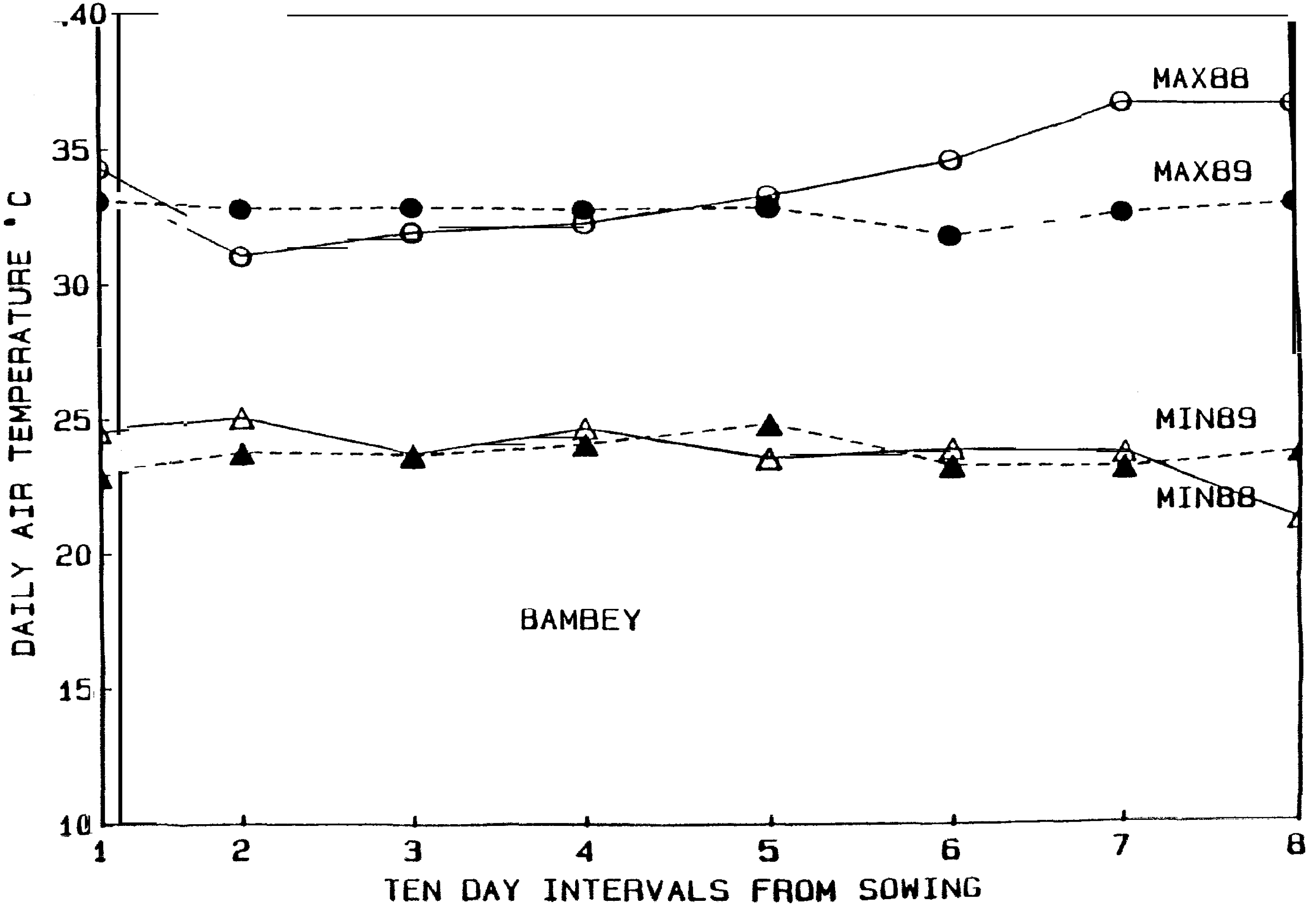

MAX88
MAX89
MIN89
MIN88
BAMBEY
DAILY AIR TEMPERATURE °C
40
35
30
25
20
15
10
1
2
3
4
5
6
7
8
TEN DAY INTERVALS FROM SOWING

Figure 6. Mean maximum and minimum air temperature for every ten day interval from sowing at Louga in 1988 and 1989.

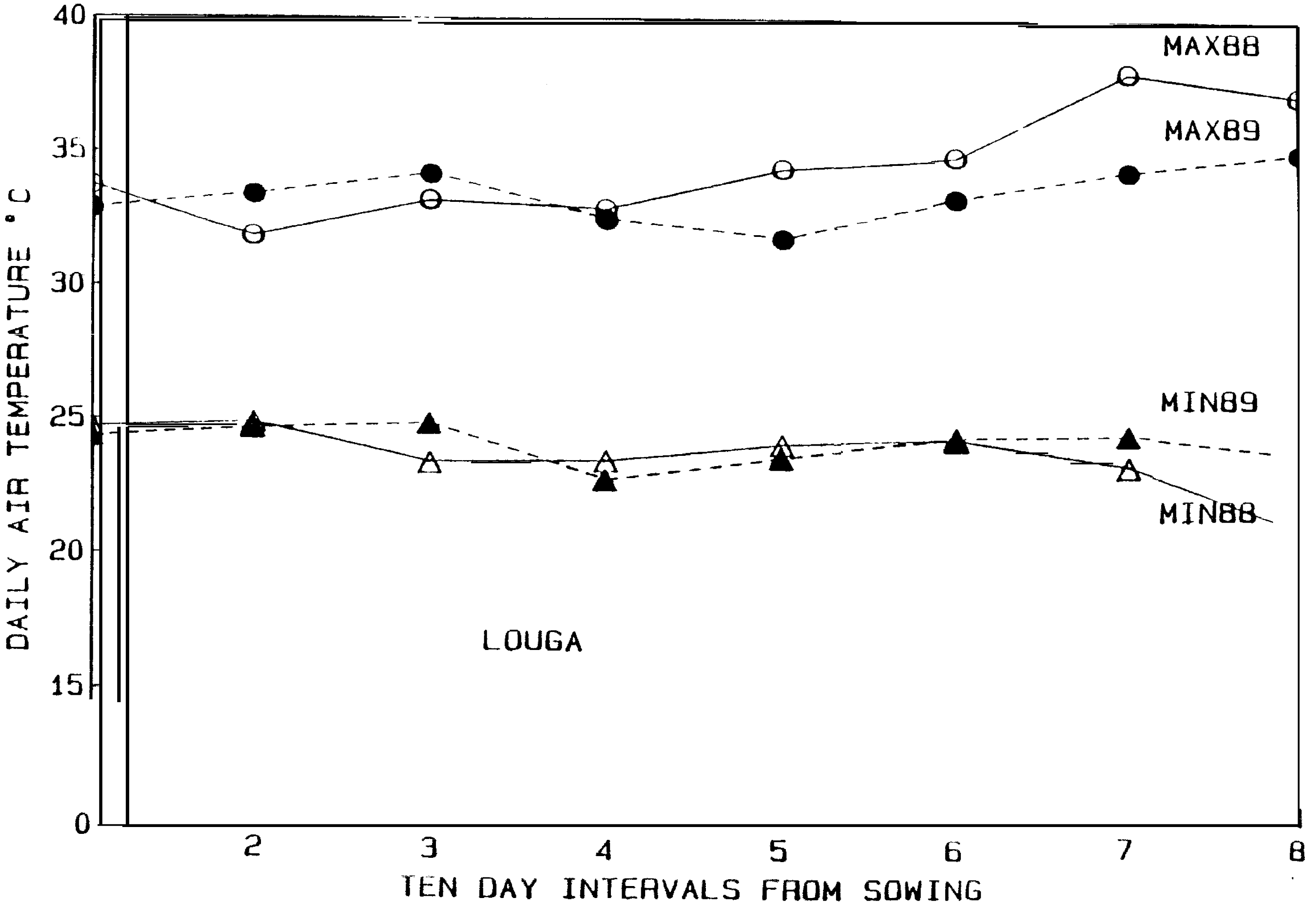

MAX88
MAX89
MIN89
MIN88
LOUGA
DAILY AIR TEMPERATURE °C
40
35
30
25
20
15
0
2
3
4
5
6
7
8
TEN DAY INTERVALS FROM SOWING

Table 3. Soil minera1 nutrient content in the O-20 cm depth at three locations in Senegal.

Minera1 content	Location		
	Bambey	Thilmakha	Louga
total N (g/kg)	CI.33	0.18	0.19
cv (%)	8.67	24.69	10.14
total P (g/kg)	0.31	0.23	0.18
CV (%)	3.80	19.04	15.74
exch. K (meq/100g)	3.17	3.06	3.11
CV (%)	5.74	15.97	9.14

cv = coefficient of variation.
Exch. K = exchangeable potassium.

Table 4. Leaf blade minera1 nutrient content of cowpea in Senegal in 1989.

Location	Mn	Fe	Zn	CU	K	P
	Minera1 concentration					
	.......(g/Mg)	....			..(g/kg)..	
Bambey	281	145	28	12	13.1	3.2
Louga	488	260	30	9	12.0	3.3
Thilmakha	477	134	24	8	8.2	2.7
LSD (0.05)	70	31	2	2	1.0	ns
signif.	***	***	***	***	***	ns

*** = significant at p = 0.005
ns = non signicant at p = 0.05
LSD for location

Table 5. Mean grain yield of cowpea for all treatments in control and fertilized plots at Bambey, Thilmakha and Louga.

Treatment	Bambey		Thilmakha		Louga	
	1988	1989	1988	1989	1988	1989
	(kg/ha)					
Control	1394	1334	671	599	616	501
Fertilized	1438	1399	930	933	875	575
Yield diff.	44	5	259	334	259	74
Fertility	ns	ns	***	***	***	*
LSD (0.05)	-	-	67	53	60	54
gen.x fert.	ns	ns	ns	ns	ns	ns

Fertility gives the significance between control and fertilized plots

LSD for the control and the fertilized plots

Gen. x fert. interaction between main treatments (cultivars) and subtreatments (fertility level).

*, ***, ns = significant at p = 0.05, p = 0.005 and non significant at p = 0.05, respectively.

Table 6. Mean hay yield of cowpea of all treatments in control and fertilized plots at Bambey, Thilmakha and Louga.

Treatment	Bambey		Thilmakha		Louga	
	1988	1989	1988	1989	1988	1989
	..a..........		(kg/ha)...............			
Control	2424	4766	530	843	461	847
Fertilized	2437	4642	784	1147	758	956
Yield diff.	13	-124	254	304	297	109
Fertility	ns	ns	***	***	***	*
LSD (0.05)		--	67	72	78	101
gen. x fert.	ns	ns	ns	ns	ns	ns

Fertility gives the significance between the control and fertilized plots.

LSD for the control and fertilized plots.

Gen. x fert. interaction between main treatments (cultivars) and subtreatments (fertility levels).

*, ***, ns = significance at p = 0.05, p = 0.005, and non significant respectively.

other two locations (Table 3). Consequently the yield responses at Thilmakha and Louga may have been due to the small amount of N (9 kg/ha) in the fertilizer treatment. The studies of Agboola (1.978) in Nigeria demonstrated that cowpea yield can respond to application of 10 kg/ha of N when the percentage of soil organic matter is as low as 0.5 or 1.0%, but not with 2% or greater organic matter. The soil organic matter was estimated to be 0.66%, 0.36% and 0.38% at Bambey, Louga and Thilmakha, respectively. Under the economic conditions prevailing in Senegal, the average yield response to starter fertilizer observed at Louga and Thilmakha would have been profitable. The genotype x fertilizer interaction was not significant in either year at any location for either grain (Table 5) or hay yield (Table 6). This indicates that trials to evaluate cultivars or varietal intercrops should give similar genotypic rankings either with or without fertilizer, Since there was no genotype x fertilizer interaction, in the subsequent analyses yields are examined which represent the average across the control and fertilized treatments.

Genotypic yield response

The overall grain and hay yields were higher at Bambey during 1988 and 1989 than at Thilmakha and Louga (Tables 5 and 6). Shoot biomass (grain plus hay) was positively correlated with seasonal rainfall (r^2 = 0.93, P

=0.002) indicating that the higher yields at Bambey were associated with wetter conditions. The higher soi.1 fertility at Bambey was an additional factor contributing to yield. Despite the high rainfall in 1989 (Table 1), the overall grain yield was higher in 1988 in all locations, possibly due to a more uniform distribution of the rain in 1988. The disease and insect pressures were also different from one location to another. Plots at Bambey suffered a severe aphid infestation coupled with mosaic virus infection of 58-57 and N'diambour in 1988, while Louga and Thilmakha suffered from hairy caterpillar in 1989.

The treatments differed significantly in grain production except at Thilmakha and Louga in 1989 (Table 7). Highest mean grain yields at Bambey (Table 7) were achieved by sole crops of intermediate (Tvx 3236), erect (Bambey 21) and spreading (N'diambour) cultivars. The genotype x year interaction was highly significant at Bambey for both grain and hay but not at Thilmakha and Louga, This indicated that the average ranking of the cultivars was not the same from year to year at Bambey. Analysis of the data from Thilmakha and Louga indicated no significant genotype x location interactions (Table 8) so it is appropriate to evaluate the mean values across these locations. Mean grain and hay yields for Thilmakha and Louga combined were highest for the varietal intercrops (Table 8).

The treatments diffe:red significantly in hay produc-

Table 7. Treatment grain yield of cowpea at three locations in Senegal.

Treatment	Bambey 1988	Bambey 1989	Thilmakha 1988	Thilmakha 1989	Louga 1988	Louga 1989
	(kg/ha)					
58-57	1171	900	697	834	831	672
N'diambour	1515	1421	910	659	a94	491
Mougne	1220	1479	662	669	750	478
Tvx 3236	1472	2184	450	669	375	550
Bambey 21	1416	1783	657	678	600	450
CB5	1580	a79	890	637	719	316
58-57/B. 21	1346	1172	1010	1184	769	625
58-57/CB5	1607	1167	1127	797	1025	722
mean	1416	1367	801	766	745	538
LSD (0.05)	266	368	334	ns	323	ns
signif.	*	**	**	ns	*	ns

*, **, ns = significant at p = 0.05, p = 0.01, and non significant, respectively.

Table 8. Mean grain and hay yields of cowpea at Bambey and Thimakha plus Louga combined averaged over 1988 and 1989.

Treatment	Location			
	Bambey		Thilmakha + Louga	
	grain	hay	grain	hay
	(kg/ha)			
58-57	1036	3674	758	766
N'diambour	1468	4388	738	908
Mougne	1349	3982	639	752
Tvx 3236	1828	3998	510	495
Bambey 21	1600	2842	596	740
California Blackeye 5	1230	2276	640	615
58-57/Bambey 21	1259	3500	896	1100
58-57/CB5	138'7	3872	917	952
mean	1391	3567	712	787
LSD (0.05)	233	818	130	122
gen. x year	***	***		
gen. x locat.			ns	ns

LSD (0.05) gives the level of significance between the different treatments
***, ns = significant at p = 0.005, and non signific:ant at p = 0.05, respectively

tion except at Louga in 1988 (Table 9). At Bambey highest mean hay yield was achieved by a sole crop of the spreading cultivar N'diambour, which also had a high grain yield (Table 7). The hay yields of the varietal intercrops were intermediate at Bambey (Table 9). Mean hay yields for Thilmakha and Louga combined (Table 8) were highest for the varietal intercrops and lowest for the erect cultivars (Bambey 21 and CB5). These data demonstrate that under water limiting conditions in infertile soils such as at Thilmakha and Louga, varietal intercrops can produce higher yields of grain and hay than sole crops of either erect or spreading cultivars. At Bambey with higher rainfall and higher soil fertility, intercrops *were* not as productive as the sole crops and would be difficult to manage due to the dense canopies that developed.

Yield component data for three contrasting genotypes in the three locations (Table 10) demonstrate that the higher yields at Bambey were associated with a *greater* number of peduncles and pods. There was little difference in number of pods per peduncle among locations. Other studies with cowpeas under different irrigation treatments have also shown a strong positive association between grain yield and the number of pods per plant (Ziska and Hall, 1983).

Land-use and Bioloaical Efficiencies

Two of the treatments consisted of varietal inter

Table 9. Treatment hay yield of cowpea at three locations in Senegal.

Treatment	Location					
	Bambey		Thilmakha		Louga	
	1988	1989	1988	1989	1988	1989
	(kg/ha)					
58-57	2147	5200	450	1094	546	975
N' diambour	2995	5787	891	994	762	987
Mougne	2767	5197	512	1122	500	875
Tvx 3236	2660	5337	328	687	294	672
Bambey 21	2477	3206	669	869	650	775
CB5	2016	2537	609	556	600	625
58-57/B. 21	1975	5025	984	1487	669	1262
58-57/CB5	2407	5337	816	1150	894	950
mean	2431	4704	657	995	609	902
LSD (0.05)	654	1.487	356	356	ns	208
signif.	*	**	**	**	ns	**

*, **, ns = significant at p = 0.05, p = 0.01, and non significant at p = 0.05, respectively.

Table 10. Yield components for three cultivars of cowpea grown in 1989 in Senegal.

	Location								
	Bambey			Thilmakha			Louga		
	ped/ plant	pod/ plant	pod/ ped	ped/ plant	pod/ plant	pod/ ped	ped/ plant	pod/ plant	pod/ ped[1]
	(no.)								
CB5	11	22	2	4	9	2.1	9	20	2.2
58-57	11	16	1.5	6	11	2.1	7	12	1.6
B. 21	14	22	1.6	5	8	1.6	11	13	1.2
mean	12	20	1.7	5	9	1.9	9	15	1.6
CV(%)	15	24	31	1	16	14	22	28	32

1 = number of peduncles and pods per plant and number of pods per peduncle.
cv = coefficient of variation.

crops with alternating rows of early erect and spreading cultivars. Their efficiencies of land use were compared with sole crops of the same cultivars. Mean LER values (Table 11) showed that the varietal intercrops had land use efficiencies for grain and hay that were 55% and 57% higher, respectively, than the sole crops at Thilmakha, and 30% and 43% higher, respectively, for grain and hay at Louga. The advantage of the varietal intercrops was smaller at Bambey with +15% for grain and +22% for hay (Table 11). The extent to which the greater droughts and lower soil fertility contributed to the greater LERs at Thilmakha and Louga, compared with Bambey, is not known. There was no difference in the LERs of fertilized compared with control plots at Thilmakha or Louga. In the studies reviewed by Hiebsch and McCollum (1987) there was a general tendency for higher LERs under less fertile soil conditions. They also showed that intercrops grown under low soil N had ATER values greater than unity, whereas intercrops under high soil N had average ATER values close to unity (Hiebsch and McCollum, 1987). In this study, the ATER values showed that the varietal intercrops were biologically more efficient than sole crops of the same cultivars (Table 11). At Thilmakha, the biological efficiencies of the intercrops for grain and hay were 30 and 44% higher, respectively, than the sole crops, while at Louga, the biological efficiencies for grain and hay were 13 and

Table 11. **Mean** values for LER and ATER for grain and hay yield of cowpea across fertilizer and years at Bambey, Thilmakha and Louga.

Location	Intercrop	LER		ATER	
		grain	hay	grain	hay
Bambey	58-57/B 21	1.05	1.07	0.97	0.98
	58-57/CB5	1.25	1.37	1.10	1.15
	mean	1.15	1.22	1.03	1.06
	LSD (0.05)	0.19	ns	-	
Thilmakha	58-57/B21	1.64	1.67	1.47	1.57
	58-57/CB5	1.38	1.50	1.14	1.32
	mean	1.55	1.57	1.30	1.44
	LSD (0.05)	ns	ns		
Louga	58-57/B21	1.12	1.47	1.06	1.32
	58-57/CB5	1.48	1.40	1.21	9.24
	mean	1.30	1.43	1.13	1.28
	LSD (0.05)	0.33	ns		

ns = non significant at p = 0.05
LSD(0.05) for the two intercrop treatments
LER = Land Equivalency Ratio.
ATER = Area x Time Equivalency Ratio.

28% higher, respectively, than the sole crops. ATER values at Bambey for grain and hay were close to 1.0 indicating little difference in biological efficiency.

The magnitude of the partial LERs show which cultivar made the major contribution to the total LERs. In 1988, the partial LERs for grain (Table 12) were higher for the early erect cultivars (Bambey 21 and CB5) at Bambey and Thilmakha, whereas in 1989, the medium cycle cultivar had the highest partial LERs in all locations. In 19 out of 24 cases, the partial LERs were greater than 0.5, indicating contributions from both cultivars to the higher LERs of the varietal intercrops (Table 12). Partial LERs for hay (Table 13) indicated that in most cases both cultivars contributed to the high LERs of the varietal intercrops at Thilmakha and Louga in both 1988 and 1989. The low partial LERs for grain and hay during 1988 for the medium cycle spreading cultivar at Bambey was partially due to the high incidence of cowpea aphids and mosaic virus. The data did not show a general suppression of partial LER in the early erect cultivars due to competition with the spreading cultivar. The data in parentheses (Table 13) demonstrated that the medium cycle spreading cultivar provided the major contribution to total hay yield in 1989 in all locations, whereas in 1988 the early erect cultivars contributed more to total yield. The data for grain exhibited similar responses (Table 12).

Table 12. Partial LERs for grain for each component cowpea cultivar in the varietal intercrop during two years in each location.

Location	Year	Intercrop treatments			
		58-57/Bambey 21		58-57/CB5	
		58-57	Bambey 21	58-57*	CB5*
Bambey	1988	0.45 (39)'"	0.59	0.48 (35)	0.66
	1989	0.71 (54)	0.30	0.73 (59)	0.54
Thilmakha	1988	0.66 (46)	0.82	0.60 (31)	0.87
	1989	0.82 (57)	0.77	0.66 (63)	0.43
Louga	1988	0.54 (58)	0.55	0.61 (48)	0.60
	1989	0.62 (67)	0.48	0.75 (81)	0.58

* Number in parentheses indicates the percent contribution of the medium cycle spreading cultivar (58-57) to the total yield of the intercrop.

Table 13. Partial LERs for hay for each component cowpea cultivar in the varietal intercrop during two years in each location.

Location	Year	Intercrop treatments 58-57/Bambey 21		58-57/CB5	
		58-57	Bambey 21	58-57	CB5
Bambey	1988	0.34 (38)*	0.55	0.39 (35)	0.78
	1989	0.66 (68)	0.50	0.76 (74)	0.80
Thilmakha	1988	0.93 (43)	0.87	0.74 (46)	0.80
	1989	0.77 (57)	0.75	0.77 (73)	0.53
Louga	1988	0.55 (42)	0.64	0.68 (38)	0.89
	1989	0.69 (52)	0.84	0.85 (86)	0.22

* Number in parentheses indicates the percent contribution of the medium cycle spreading cultivar 58-57 to the total yield of the intercrop.

The drought during the vegetative stage at Louga (Figure 3) and Thilmakha (Figure 4) stressed the early erect cultivars and could have been responsible for the yield advantage of the late cultivar, 58-57, in 1989. Mosaic virus infection could have contributed to the low yield of 58-57 in 1988. This year-to-year variation in the type of cultivar making the major contribution to total yield illustrates the mechanism whereby varietal intercrops could have enhanced yield stability. Presumably, the erect cultivars, which were early had completed podding by the time the spreading cultivars encroached on their space. The year-to-year variation in partial LERs for particular cultivars also illustrates the mechanism whereby varietal intercrops could have stabilized yield during the two years of studies.

Stability and adaptation of the cultivars

Regression analysis was conducted on the mean yield of each genotype in a given environment against an environmental index consisting of the mean yield of all genotypes in that environment (Tables 14 and 15). The high r^2 values demonstrate that the linear regression was appropriate. With respect to grain yield, the landrace 58-57 and the two varietal intercrops had the highest "a" value (y intercept) and the lowest "b" value (regression coefficient). This means that the late cultivar (58-57) and the two varietal intercrops consisting of alternating rows of

Table 14. Linear regression analysis over six environments (3 locations x 2 years) for treatment grain yield versus environmental mean grain yield in cowpea.

Treatment	Mean yield (kg/ha)	a	b	s.b.	r^2
58-57	851	461	0.42	0.13	0.70
N'diambour	982	-48	1.10	0.13	0.95
Mougne	876	-81	1.02	0.15	0.92
Tvx 3236	950	-714	1.77	0.46	0.79
Bambey 21	931	-402	1.42	0.21	0.92
CB5	837	-64	0.96	0.32	0.69
58-57/B. 21	1018	446	0.61	0.22	0.65
58-57/CB5	1065	406	0.70	0.25	0.66

a = Y intercept
b = coefficient of regression
s.b = standard error of the slope (b)
r^2 = coefficient of determination
X = mean grain yield of each cultivar in each environment.
Y = mean grain yield of all cultivars in each environment.

Table 15. Linear regression analysis over six environments (3 locations x 2 years) for treatment hay yield versus environmental mean hay yield in cowpea.

Treatment	Mean yield (kg/ha)	a	b	s.b.	r^2
58-57	1729	-183	1.10	0.07	0.99
N'diambour	2069	-63	1.24	0.03	0.99
Mougne	1829	-141	1.15	0.03	0.99
Tvx 3236	1678	-447	1.24	0.02	0.99
Bambey 21	1441	293	0.67	0.09	0.94
CB5	1157	257	0.52	0.08	0.92
58-57/B. 21	1900	241	0.97	0.10	0.95
58-57/CB5	1926	46	1.10	0.05	0.98

a = Y intercept
b = coefficient of regression
s.b. = standard error of slope (b)
r^2 = coefficient of determination
X = mean hay yield of each cultivar in each environment.
Y = mean hay yield of all cultivars in each environment.

58-57 and Bambey 21 or CB5 were more stable and performed better in the stress environment. However, the cultivar 58-57 had low mean yield whereas the two varietal intercrops had the highest mean yields. A more generalized interpretation of varietal adaptation is'shown by plotting the regression coefficient against the genotypic mean yield (Figure 7). The varietal intercrops were well adapted to all environments because they had the highest mean grain yields. They also had low regression coefficients, indicating above average stability and better adaptation to unfavorable environments (Finlay and Wilkinson, 1963). N'diambour was reasonably adapted to all environments because of its high grain yield and its regression coefficient of 1.10, whereas 58-57 was only adapted to the lower yielding environments with a regression coefficient of 0.42. Tvx 3236 was very responsive to environmental changes. With a regression coefficient of 1.77, it is specifically adapted to favorable environments.

Results for hay (Table 15 and Figure 8) indicated that all the treatments except the two erect cultivars (Bambey 21 and CB5) had high potential for hay production in that they had high hay mean yields and regression coefficient close to unity. N'diambour and the two varietal intercrops were best adapted to all environments in that they the high hay yields and their regression coefficients were around 1.0.

Figure 7. Relationship of cowpea cultivar adaptation (regression coefficient) to cultivar mean grain yield in all environments. Regression coefficient (b) was taken from analysis shown in Table 14.

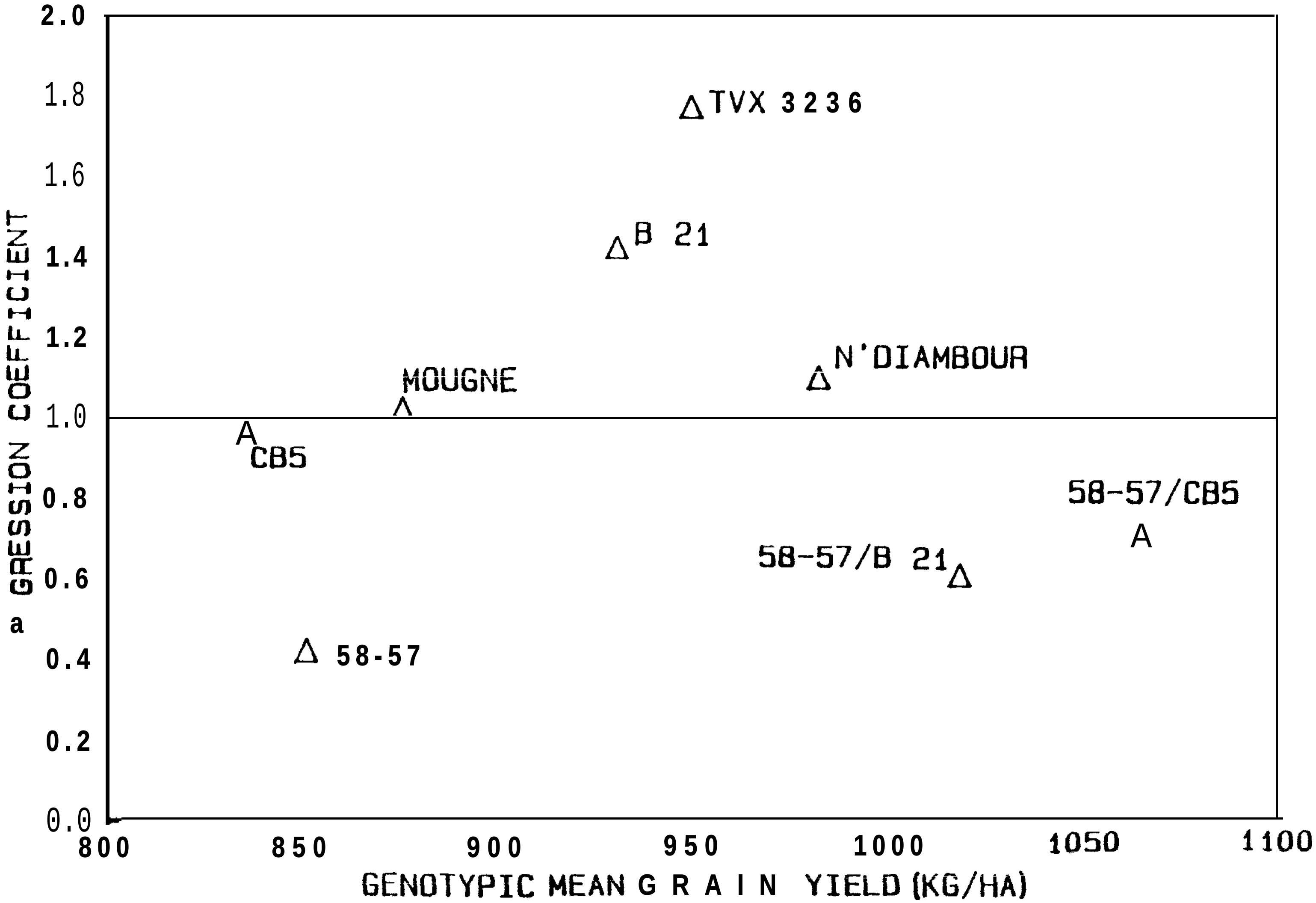
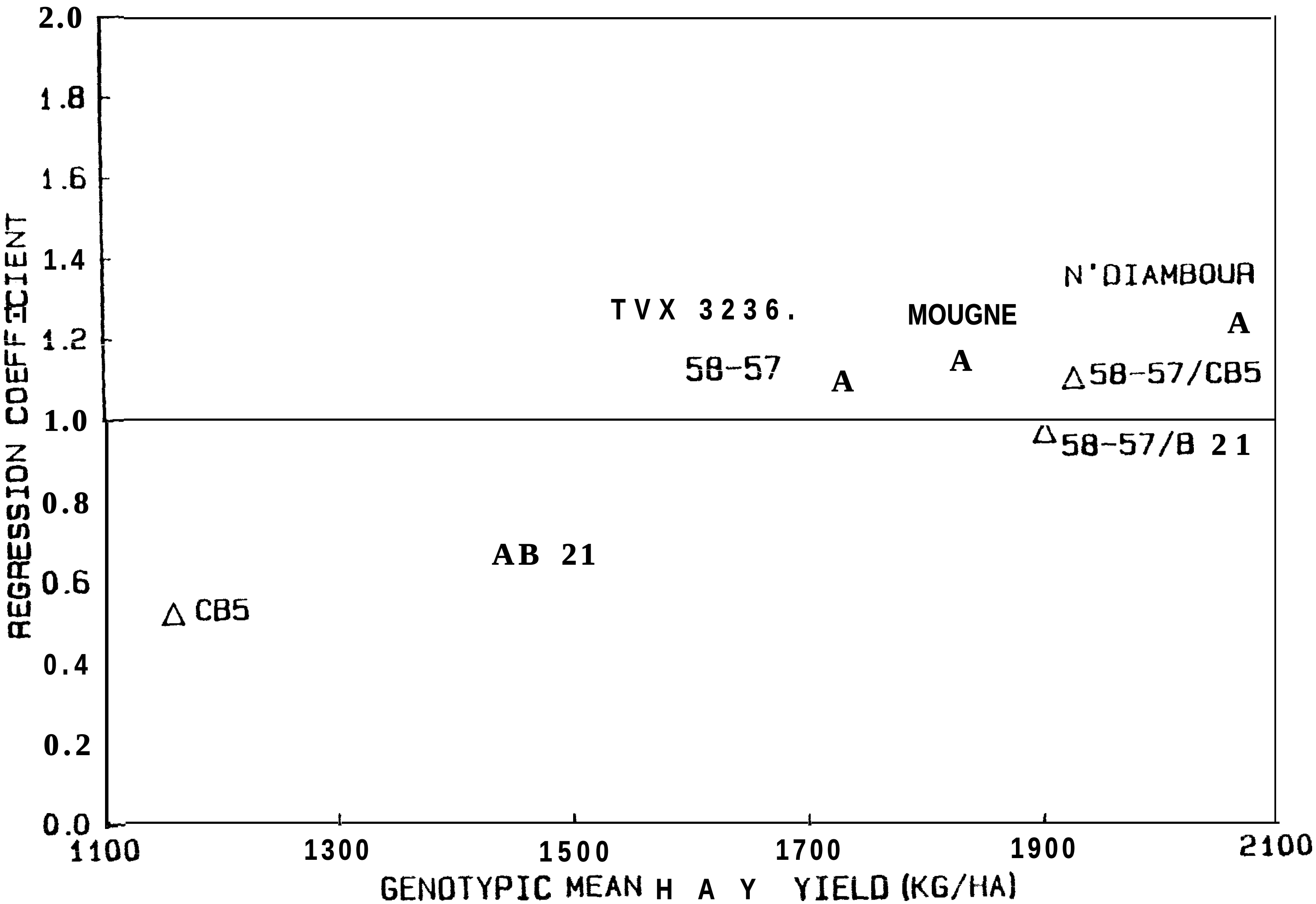

2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
a GRESSION COEFFICIENT
TVX 3236
B 21
N'DIAMBOUR
MOUGNE
CB5
58-57/CB5
58-57/B 21
58-57
800
850
900
950
1000
1050
1100
GENOTYPIC MEAN G R A I N YIELD (KG/HA)

Figure 8 Relationship of cowpea cultivar adaptation (regression coefficient) to cultivar mean hay yield in all environments. Regression coefficient (b) was taken from analysis shown in Table 15.


2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
REGRESSION COEFFICIENT
1100
1300
1500
1700
1900
2100
GENOTYPIC MEAN HAY YIELD (KG/HA)
TVX 3236.
58-57
MOUGNE
N'DIAMBOUR
58-57/CB5
58-57/B 21
AB 21
CB5

The spreading cultivars (Mougne and 58-57) and the semi-erect cultivar (Tvx 3236) also had moderately high hay production and their regression coefficients of 1.15, 1.10, and 1.24, respectively, indicated reasonable stability. The two early-erect cultivars (Bambey 21 and CB5) were only adapted to unfavorable environments (low mean grain yields and low regression coefficients). Their small, erect, and determinate growth habit was incompatible with high hay production. In summary, the linear regression analysis showed that in terms of grain production, the varietal intercrops were better adapted than the cultivars grown as sole crops especially in the low yielding environments, Thilmakha and Louga. In terms of hay production, the varietal intercrops and N'diambour were well adapted to all environments.

CONCLUSIONS

Intercrops of early-erect and medium-cycle spreading cowpea cultivars were shown to be more effective than sole c:rops of these cultivars in dry locations with infertile soils in Senegal. In the Thilmakha and Louga locations, farmers growing both types of cultivars would have to plant 42 or 50% more land area of the sole crops to obtain the same grain or hay yields as the varietal intercrops. Farmers in these locations who are seeking the highest yielding system should also choose the varietal inter-crops. They had higher mean grain and hay yields than any of the cultivars tested as sole crops, and above average yield stability.

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