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ON-FARM EXPERIMENTS WITH MILLET IN NIGER: CROP ESTABLISHMENT, YIELD LOSS FACTORS AND ECONOMIC ANALYSIS

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SUMMARY

Results of farm-level experiments with pearl millet are reported from four villages in semi-arid Niger in 1982 and 1983. Crop establishment, yield loss factors (insects, diseases, striga) and economics of new practices were studied in a randomized design which included density, fertility, cultivar, and intercropping with cowpea as treatments. Improved cultivars did not establish significantly better than local ones, but fertilizer occasionally improved establishment. Incidence of yield loss factors was low, and only small effects of cultivar and fertilizer were seen. Fertilizer increased grain yields of the local cultivar by as much as 153%. The use of fertilizer and improved cultivars increased grain yields by as much as 171% over an unfertilized local millet. Even without government subsidies, fertilizer use was profitable for 56% of farmers on all cultivars. In general, fertilizers and improved cultivars had a small positive impact on profitability, with little adverse impact on grain yield variability, so that they could be recommended to farmers with some prospect of success. The intercropping treatment failed in both years, and would have to be modified before extension.

J. McIntire y L. K. Fussell: *Experimentos en la explotación agrícola con mijo en Níger: establecimiento del cultivo, factores de pérdida de rendimiento y análisis económico.*

RESUMEN

Se presentan informes de los resultados de experimentos a nivel de explotación agriícola realizados con mijo perla en cuatro aldeas en la región semiárida de Niger, en 1982 y 1983. El establecimiento del cultivo, los factores de pérdida de rendimiento (insectos, enfermedades, striga) y la rentabilidad de nuevos regímenes fueron estudiados en un diseño aleatorizado que incluía como tratamientos la densidad, fertilidad, cultivar, y cultivo intercalado con caupí. Los cultivares mejorados no se establecieron de manera significativamente mejor que los locales, pero de vez en cuando el establecimiento se vio mejorado por el uso de fertilizantes. La incidencia de factores de pérdida de rendimiento fue baja, y sólo se observaron efectos reducidos del cultivar y fertilizante. El uso de fertilizante aumentó los rendimientos de grano del cultivar local hasta en un 153%. El uso fertilizante y cultivares mejorados aumentó los rendimientos de grano hasta en un 171% en comparación con un mijo local sin fertilizar. Aun sin subvenciones del gobierno, el uso de fertilizantes resultó rentable para 56% de los agricultores en todos los cultivares. En general, los fertilizantes y cultivares mejorados ejercieron un pequeño efecto positivo sobre la rentabilidad, con poco efecto adverso sobre la variabilidad del rendimiento de grano, pudiéndose recomendarlos a los agricultores con buenas espectativas para el éxito. El tratamiento de cultivo intercalado fracasó en ambos años, y tendriá que modificarse antes de ampliarlo.

INTRODUCTION

Pearl millet (*Pennisetum americanum* (L.) Leeke) is a major crop in the zones of West Africa receiving less than 800 mm annual rainfall. In spite of the crop's

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importance, little is known about factors limiting its production on farms. Among factors identified on experimental stations are poor establishment (ICRISAT, 1983b), plant diseases, insects, weeds, and the absence of chemical fertilizers and improved cultivars.

Previous work in farmers' fields has shown that local millets established better than an improved cultivar in northern Burkina Faso (ICRISAT, 1983a, ICRISAT, 1983b) and that there was an interaction between cultivar and soil preparation. If these results are confirmed at the farm level, then the improvement of crop establishment should be a goal of screening programmes. If cropping practices significantly affect establishment, then they must be studied so that the best can be incorporated into extension packages.

Important among pests of pearl millet are downy mildew (*Sclerospora graminicola*), ear-head caterpillar (*Raghuva albipunctella*), striga (*Striga hermontheca*) and stemborers (*Acigona ignefusalis*). Preventing these attacks or reducing their effects is a major research objective in West Africa. Estimating the incidence of these pests and the yield losses caused by them is therefore important in defining research priorities.

Although there has been some success in selecting improved millet cultivars (Kowal and Kassam, 1978), they have been little adopted by farmers. Similarly, although fertilizer recommendations have been developed for millet, use remains low. An important hypothesis, therefore, is that current cultivar and fertilizer recommendations are not profitable on typical farms.

This paper reports evidence on the factors affecting pearl millet production in western Niger in 1982 and 1983 from on-farm experiments conducted by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). The data comprise approximately 640 observations from farmers' fields, including results on crop establishment, pests, yields, introduced cultivars and chemical fertilizers. As far as the authors know, this is the largest set of farm-level data on millet in West Africa.

STUDY SITES

Some characteristics of the four villages studied are presented in Table 1. Pearl millet is the main crop, occupying more than 95% of the cultivated area. In the villages (Sadeize Koira and Samari) north of the national capital of Niamey, fallows are extensive, the mean cropped area is about 15 ha household^{-1} and population density is about 10 persons km^{-2}. In the villages south of Niamey (Gobery and Fabidji), population density is 50 persons km^{-2} and the cropped area is 10 ha household^{-1}. Cash crops are non-existent and the principal sources of cash income are livestock and salaried labour in neighbouring countries.

Total annual rainfall in the northern villages averages about 500 mm; in the southern villages it is nearer 600 mm (Sivakumar *et al.*, 1982). In 1982 and 1983 the total rainfall was well below the long-term averages, and early season rainfall was highly variable around the expected values (54 mm in the northern and 60 mm in the southern villages).

Table 1. *Village characteristics*

	Sadeize Koira	Samari	Gobery	Fabidji
	(14° 10′ N, 2° 0′ E)		(12° 43′ N, 2° 48′ E)	
Average annual rainfall (mm)	500	500	600	600
Total rainfall, 21 May to 30 September (mm)				
1982	240	200	570	530
1983	330	340	335	395
Planting time rainfall, 21 May to 17 June (mm)				
1982	41	34	113	83
1983	21	22	19	34
Number of households sampled	26	24	28	29
Soil characteristics in 1983†				
P_2O_5 (ppm)				
mean	2.87	2.91	2.29	2.89
SD	0.99	0.89	0.49	2.35
organic matter (%)				
mean	0.17	0.19	0.24	0.29
SD	0.03	0.03	0.04	0.06
clay (%)				
mean	3.98	4.49	3.96	4.00
SD	0.86	1.21	0.46	1.28
pH				
mean	4.35	4.45	4.27	4.65
SD	0.23	0.48	0.31	0.57

† No soil measurements were taken in 1982.

Soils in the villages are sandy (Alfisols and Entisols), acid and have little organic matter (Table 1). (The greater OM content in the southern villages probably results from a greater livestock density.) Ambient temperatures at planting time in May and June are about 40°C at mid-day. Soil temperatures in the upper profile at this time can exceed 50°C, and may affect crop establishement.

Cultivation is with hand tools, and only one farmer in the sample of 107 uses animal traction. Farmers typically do not prepare the seedbed before planting. When the rains begin, millet is planted by digging a shallow hole (roughly 15 cm deep), dropping 30 to 40 seeds into it, and covering it with soil compressed by the foot. Two weedings are done, beginning 15 days after planting and continuing until 60 days thereafter.

TREATMENTS AND DATA COLLECTION

In 1982, experiments were begun with randomly selected farmers to estimate millet production parameters. The experiments were conducted in Sadeize Koira and Gobery in 1982, and in all villages in 1983. A literature review guided the choice of treatments for density, cultivar, fertilizer application rates and intercropping. The treatments chosen are the object of major extension efforts in Niger, so identifying constraints to their adoption can have a high payoff.

Each farmer applied four treatments to his plots. Treatment 1 (T1) comprised of the local millet cultivar, without chemical fertilizer, and with the traditional millet density (about 5000 pockets ha^{-1}); Treatment 2 (T2) comprised of the local millet, with 18 kg P ha^{-1} as single superphosphate (0-18-0) broadcast before planting, 30 kg N ha^{-1} as urea (46-0-0), half broadcast 15 days after planting and half broadcast 30 days after planting, and with a density of 10 000 pockets ha^{-1}; Treatment 3 (T3) comprised of improved millet, with the same fertilizer and millet density as T2; Treatment 4 (T4) comprised of the improved millet, with the same fertilizer and millet density as T2 and T3, plus cowpea (*Vigna unguiculata* L. Walp) intercropped between every second row of millet. Fertilizer and seed were provided free by ICRISAT.

The improved cultivar in 1982 was CIVT (Composite Intervarietale de Tarna), developed by the Institut National de Recherche Agronomique du Niger (INRAN). In 1983, the cultivar HKP (Haini Kiri Precoce) was used in Sadeize Koira and Samari while CIVT was used in Gobery and Fabidji. HKP is an early millet developed from local parents by INRAN. The cycle of CIVT is 100-110 days, while that of HKP is 90-100 days. The cowpea used was TN 88-63, a semi-erect cultivar.

Farmers did all the planting, fertilizer application and cultivation on their own fields. On each farm four treatments were used in grouped plots, separated by 2 m alleys. Because the distance between farmers' fields in the same village was as great as 7 km, this separation of treatments grown by different farmers tended to create block effects. In 1982, the treatment size was 500 m^2, giving a total cultivated area of 2000 m^2; in 1983, the treatment size was 1000 m^2, giving a cultivated area of 4000 m^2. The large plot sizes were dictated by the need to collect representative labour data.

Field staff took soil samples before the first rains in 1983. Ten samples were taken from each treatment for each farmer. The 10 treatment samples were mixed and a sub-sample drawn for analysis. Owing to a lack of reagents, it was sometimes necessary to mix the treatment samples for a given farmer, but samples were never mixed between farmers.

Crop establishment

Field staff assessed crop establishment roughly three weeks after planting by counting the total number of pockets and the number of 'viable' pockets (those with at least one surviving plant) in three rows down the middle of the plot in one direction, and repeating the procedure in the other direction. Establishment was defined as the proportion of viable:total pockets. Plots were excluded from the analysis if they had been replanted before the counts.

Yields

Because of the large plot sizes only sub-plots were harvested. In 1982, three 30 m^2 sub-plots were taken in each treatment for each farmer; in 1983, three 50 m^2 sub-plots were taken. Field assistants harvested the yield plots, taking a random sample of heads (1.0 kg in 1982, and 2.0 kg in 1983) from each treatment for threshing, and made other technical observations. To estimate grain yield, the unthreshed harvest per treatment was weighed and multiplied by the threshing coefficient. To estimate straw yield, all fresh matter from the yield sub-plot was weighed.

Yield loss factors

When harvesting the yield sub-plots, observers counted pockets attacked by striga, downy mildew and chibras millets. Chibras (Hausa) millets are outcrosses of cultivated millets with *Pennisetum violaceum* which shatter and reduce yields. Each pocket was scored for chibras on a 0–3 scale: 1, one chibras plant; 2, two chibras plants; 3, three chibras plants. Each pocket was scored for downy mildew on a 0–4 scale: 1, only axillary tillers infected; 2, less than 50% of main tillers infected; 3, between 50 and 99% of main tillers infected; 4, all tillers infected. Each pocket was scored for the presence (1) or absence (0) of striga. For chibras, downy mildew and striga, the variable used for analysis was the average score per pocket multiplied by 100.

In 1982, the 1.0 kg threshing sample from each treatment was scored for Raghuva damage on a 1–10 scale. In 1983, 10 ears from each 2.0 kg threshing sample were chosen randomly and scored with the same scale. In 1982, the variable for analysis was the total score divided by the number of ears, multiplied by 100. In 1983, because only 10 ears were scored, the variable was the total score.

Counts of stemborers were made from harvested stalks. A sample of 15 stalks was taken at random from one of the three yield sub-plots in each treatment. The stalks were split and the percentage of total internodes bored by the insect was used as the variable for analysis.

Estimates of the yield effects of these pests were made by regression analyses, in which the scores were the independent variables and millet grain yield was the dependent variable.

Labour inputs

Enumerators residing in the villages recorded labour inputs during weekly interviews with farmers. Weekly visits to record labour use may cause recall bias – that is, the tendency of farmers to inflate estimates of working periods (Coleman, 1983) as time elapses between the working day and the interview day. However, because farmers carried out plot operations on the same day for all treatments, such bias should apply uniformly and not affect treatment comparisons.

Prices for economic analysis

Calculated economic and official prices are shown in Table 2. The analysis with economic prices reveals the profitability of cropping practices in the absence of government actions affecting prices. For millet grain and straw,

Table 2. *Prices used in budget calculations (CFAF† kg^{-1})*

	Post harvest market price	Official price
Output		
Millet grain		
1982 price	123	80
1983 price	130	85
Millet straw		
1982 price	8	none
1983 price	8	none
	Import price to Niamey	Official price
Input		
Urea		
1982 price	165	50
1983 price	165	50
Single superphosphate		
1982 price	125	35
1983 price	125	35

† 1 US dollar was on average equivalent to 382 Communaute Financiere Africaine Francs (CFAF) in 1982 and 1983.

economic prices are those in markets adjacent to the villages. For urea and superphosphate, economic prices are import prices to the capital.

The analysis with official prices shows the effects of government price policies on incentives to use new practices. For millet grain, producer prices are announced by the government before the cropping season. There are no official millet straw prices, so the market prices are used. For urea and superphosphate, the government retail prices are used. There was a heavy subsidy on fertilizers.

Budget calculations

The indicator of profitability is the value:cost ratio (VCR). This is defined as the difference between the gross revenues (price × yield) of T2 (or of T3 or T4) and T1, divided by the fertilizer cost of T2 (or T3 or T4). The VCR is interpreted as the incremental return to the treatment over current farmers' practice. The difference between gross revenue and fertilizer cost is defined as the net revenue of a treatment. Because labour costs did not differ significantly among treatments, they were not considered in the economic analysis.

Four comparisons were made in each year and village. First, the effect of fertility and density on the profitability of the local cultivar was estimated by comparing T2 to T1. Second, the effects of fertility, density, and improved cultivar were estimated by comparing T3 and T4 to T1. Each comparison was made at economic prices and at official prices. It proved impossible to analyse the intercropping treatment (T4) separately, because most of the cowpea grain and hay yields were zero, so T3 and T4 are combined in the analysis, and denoted as T3&4.

Because the economic analyses use paired comparisons, farmer (block) effects are removed and the standard errors of the mean differences between treatments reduced. This has the undesirable effect of diminishing the sample size in Fabidji because many farmers mistakenly harvested their treatments before the yield sub-plots were harvested.

RESULTS

Planting and establishment

Farmers almost always planted immediately after the first rains in May or in June (Table 3). In 1983, more than 88% of all plots were planted within two days of the first rain; in 1982, the distribution was more dispersed.

In 1982, the mean establishment was greater than 84% in both villages (Table 4) and roughly 80% of farmers achieved greater than 80% establishment. Establishment in 1983 was poorer than in 1982, due to insufficient rains soon after planting. Establishment distributions were significantly ($P<0.01$) negatively skewed in five village/year combinations.

Factors determining establishment

Variables affecting establishment were examined by multiple regression analysis. The equations, estimated by least squares using the continuous variables shown in Table 5 and with dummy variables (not shown in Table 5) representing farmers, were significant ($P<0.01$) in five instances. Cultivar was significant ($P<0.05$) in Sadeize Koira in 1982, and in Samari in 1983. The

Table 3. *Distribution of planting dates*

	1982		1983			
	Sadeize Koira	Gobery	Sadeize Koira	Samari	Gobery	Fabidji
Number of plots†	104	112	104	96	112	115
Distribution of observed planting dates						
30 April–13 May	0	0	0	0	4	33
14–20 May	0	0	0	0	20	30
21–27 May	0	92	0	0	0	46
28 May–3 June	20	16	4	0	0	4
4–10 June	83	4	0	2	4	2
11–17 June	0	0	96	13	0	0
18–24 June	0	0	4	81	77	0
25 June–1 July	1	0	0	0	5	0
Days from rain to planting						
0	1	0	4	46	8	19
1	21	40	43	45	88	80
2	38	16	45	5	12	16
3	33	8	4	0	1	0
4	11	16	8	0	0	0
>4	0	32	0	0	1	0
Number of plots replanted	46	12	60	11	26	35
1 replanting	46	12	51	11	26	34
2 replantings	0	0	9	0	0	1

† Numbers of plots shown in this table are valid for other tables, except where otherwise noted.

Table 4. *Millet establishment and stand density*

	1982		1983			
	Sadeize Koira	Gobery	Sadeize Koira	Samari	Gobery	Fabidji
Number of plots†	104	110	92	91	86	113
			Establishment values (%)			
All observations						
mean	84	90	50	74	86	73
SD	19.3	9.1	24.6	16.7	20.7	24.6
minimum	10	52	1	19	22	9
skew	−2.305***	−1.866***	−0.058	−0.827***	−1.857***	−0.932***
Treatment 1						
mean	83	91	39	71	89	68
SD	14.6	9.4	22.6	18.4	17.4	21.4
Treatment 2						
mean	83	90	60	79	86	77
SD	23.8	9.1	23.4	14.9	21.0	22.3
Treatment 3&4						
mean	85	90	52	72	85	74
SD	19.1	9.4	24.7	16.8	21.0	27.5
			Expected stand density at establishment (1000s pockets ha^{-1})			
All observations						
mean	9.7	7.2	10.0	7.0	6.5	6.3
SD	1.94	1.88	2.02	1.84	1.6	1.8
minimum	5.5	3.2	5.8	4.0	3.2	2.8
maximum	14.0	13.0	14.7	12.0	10.2	10.8
skew	0.078	0.345	0.053	0.901***	0.271	0.482**
			Actual stand density at establishment (1000s pockets ha^{-1})			
All observations						
mean	7.2	6.0	3.2	4.1	5.4	4.4
SD	2.82	1.98	2.96	2.22	2.43	2.11
minimum	0.1	1.2	0.0	0.2	0.4	0.2
maximum	12.4	10.9	11.5	10.7	10.2	9.2
skew	−0.733***	−0.148	1.120***	0.828***	−0.232	0.385***
Treatment 1						
mean	5.8	6.0	1.8	3.9	3.7	3.0
SD	1.91	2.11	1.56	2.42	1.67	1.53
Treatment 2						
mean	7.2	6.1	4.6	4.7	5.9	4.4
SD	3.13	2.12	3.66	2.43	2.49	1.94
Treatment 3&4						
mean	8.0	6.1	3.3	3.9	5.9	5.1
SD	2.81	1.86	2.88	1.94	2.49	2.06

***, **, and * denote significance at $P<0.01$, 0.05 and 0.1, respectively.
† The number of plots is sometimes less than shown in Table 3 because some plots were replanted before density and establishment were observed.

delay from the day of rainfall to the day of planting had a significantly ($P<0.01$) negative effect only in Gobery in 1982. Fertilizer had a significant ($P<0.10$) effect in two villages in 1983. In most instances organic matter, P_2O_5 and N had no effects on establishment.

Table 5. *Establishment regression coefficients (t-values in parenthesis)*

	1982		1983		
	Sadeize Koira	Gobery	Sadeize Koira	Samari	Fabidji
Management variables					
Days planted after rain		−2.2 (−6.276***)			
Fertilizer applied			15.0 (4.112***)	6.1 (1.941*)	7.2 (1.292)
Cultivar	13.4 (2.140**)			−11.2 (−3.309***)	9.49 (1.391)
Plant location					
Near household			−25.9 (−4.334***)		
Far from household		3.8 (1.936*)	9.6 (1.942*)		
Soil variables					
N content	129.3 (1.528)				
Organic matter			121.2 (2.333**)		−70.2 (−1.863*)
Clay content				−2.5 (−2.256**)	−12.1 (−6.789***)
Interactions					
Planting delay × cultivar	−4.7 (−1.968*)				
Bush plot × cultivar		−0.9 (−0.478)	12.4 (1.938*)	10.5 (2.776***)	−16.7 (−2.374**)
Adjusted r^2	0.427	0.356	0.711	0.627	0.521
Number of observations	104	106	92	90	95
F-value	8.861***	6.854***	14.791***	11.915***	5.738***

***, ** and * denote significance at $P < 0.01$, 0.05 and 0.10, respectively.

Replanting

A plot was counted as replanted if any part of it had been replanted (Table 3). In 1982, between 10 and 45% of plots were replanted; in 1983, the proportions ranged from 11 to 58%, replanting most often being necessary at Sadeize Koira. In 1983, the delay between planting and replanting ranged from three to 44 days, with most delays being between 21 and 30 days. Treatments 3 and 4 contributed to significantly higher ($P < 0.01$) replanting in 1982.

Yield loss factors

Except for stemborer and chibras, yield loss factors were absent from many of the plots, so that nearly all distributions were significantly ($P < 0.01$) positively skewed (Tables 6 and 7). Because the distributions by farmer (block) were heteroscedastic - that is, the mean and variance of variables across farms were correlated - the analysis of variance was not valid. Visual inspection of the data (not recorded in this paper) revealed large differences between village,

Table 6. *Distribution of chibras and stemborer scores*

	1982		1983			
	Sadeize Koira	Gobery	Sadeize Koira	Samari	Gobery	Fabdji
			Chibras score			
All observations						
valid n	99	108	100	95	103	90
n of values ⩽ 1.0	4	2	4	4	2	1
mean	36	38	11	9	8	10
SD	27.3	30.8	10.5	6.4	5.2	7.8
median	34	30	8	8	7	7
skew	0.594***	1.808***	2.035***	0.999***	1.488***	1.223***
Treatment 1						
valid n	25	27	22	23	26	22
mean	55	36	15	8	9	8
SD	24.9	20.3	13.2	4.9	6.8	5.9
Treatment 2						
valid n	24	27	24	26	25	24
mean	47	41	13	11	9	13
SD	25.8	29.9	9.7	6.1	4.0	9.0
Treatment 3&4						
valid n	50	54	54	46	52	44
mean	21	38	7	7	7	9
SD	19.9	35.7	8.4	6.9	4.6	7.6
			Stemborer score			
All observations						
valid n	99	108	100	95	103	90
n of values ⩽ 1.0	0	1	0	0	0	1
mean	23	21	13	13	25	23
SD	11.7	9.7	4.2	5.8	8.8	11.3
median	22	21	13	12	25	21
skew	1.211***	0.274	0.868***	0.866***	0.714***	0.623***
Treatment 1						
valid n	25	27	22	23	26	22
mean	26	22	14	10	24	23
SD	14.8	9.3	4.7	5.5	9.8	11.8
Treatment 2						
valid n	24	27	24	26	25	24
mean	23	21	13	14	23	24
SD	13.0	9.2	3.4	6.5	7.6	10.1
Treatment 3&4						
valid n	50	54	54	46	52	44
mean	22	21	13	13	27	24
SD	9.1	10.3	3.8	4.6	8.7	12.0

*** denotes significance at $P < 0.01$.

year, and farmer means for the yield loss factor variables, but no statistical analysis was done.

To estimate treatment effects, scores were recorded with the intervals 0–1.0, 1.1–10.0 and 10.1–100, and a chi-square test performed (Tables 6 and 7). For chibras, treatment was significant ($P < 0.05$) in five cases, supporting the hypothesis that the improved cultivars used in T3 and T4 had less chibras infestation. For stemborer, treatment was significant ($P < 0.05$) once. The incidence of downy mildew, striga and ear-head caterpillar was extremely variable, and there

Table 7. *Distribution of downy mildew, ear-head caterpillar and striga scores*

	1982		1983			
	Sadeize Koira	Gobery	Sadeize Koira	Samari	Gobery	Fabidji
Downy mildew score						
valid n	99	108	104	95	103	90
n of values ≤ 1.0	97	53	75	81	7	26
mean	2	3	0	0	3	3
SD	14.1	7.9	0.4	0.3	2.0	3.3
median	1	1	0	0	2	2
skew	6.926***	4.428***	1.902***	4.520***	0.878***	1.976***
Ear-head caterpillar score						
valid n	99	108	104	95	103	90
n values ≤1.0	50	10	32	52	60	6
mean	3	17	3	1	1	5
SD	4.5	12.3	3.2	0.1	0.9	3.7
median	0	14	1	0	0	5
skew	1.807***	1.293***	2.155***	1.227***	1.662***	0.702***
Striga score						
valid n	99	108	104	95	103	90
n of values ≤1.0	83	97	72	52	81	37
mean	1	1	2	12	2	10
SD	2.9	2.8	5.1	2.0	9.6	15.2
median	0	0	0	0	0	0
skew	5.127***	4.659***	3.495***	1.736***	5.834***	1.937***

*** denotes significance at $P<0.01$.

was only one significant ($P<0.05$) treatment effect in 1982 on ear-head caterpillar.

Yields and economic analysis

The descriptive statistics for grain yield, straw yield and weeding labour are shown in Table 8. Year, village and treatment had significant ($P<0.01$) effects on grain and straw yield. The grain yields of T2 and T3&4, which provide an estimate of the cultivar effect in the presence of fertilizer, were very similar. The labour required for weeding (the sum of labour used for the first and second cultivations) was 80% of total labour, excluding harvest. There was no significant treatment effect on the labour used for weeding, implying that the density, fertility, and cultivar practices did not increase the labour requirement.

T2 was not profitable (Table 9) at economic prices. Only in Gobery in 1983 was the VCR significantly greater than 1.0 ($P<0.05$); in Sadeize Koira in 1982 it was significantly less than 1.0 ($P<0.01$). At official prices, the heavy fertilizer subsidy made T2 significantly better ($P<0.05$) than T1 in four cases. At economic prices, T3&4 was significantly ($P<0.05$) more profitable than T1 in two villages but significantly less in one village in 1983. At official prices, T3&4 was significantly better ($P<0.01$) than T1 in five comparisons.

Village and year effects on net revenue were examined to see if these affected the profitability of the new practices. There were significant ($P<0.01$) village and year effects in both comparisons, though year × village interactions

Table 8. *Grain yield, straw yield and weeding labour*

	1982		1983			
	Sadeize Koira	Gobery	Sadeize Koira	Samari	Gobery	Fabidji
			Millet grain yield (kg ha⁻¹)			
Treatment 1						
n	25	27	22	23	26	22
mean	168	190	264	349	166	278
SD	115	99	151	134	130	171
Treatment 2						
n	24	27	24	26	25	24
mean	277	413	464	567	420	408
SD	125	195	204	165	158	242
Treatment 3&4						
n	50	54	54	46	52	44
mean	334	346	533	544	450	350
SD	180	142	193	261	204	189
			Millet straw yield (kg ha⁻¹)			
Treatment 1						
n	25	27	22	23	26	22
mean	474	770	1485	2369	788	1888
SD	327	442	1025	908	615	1185
Treatment 2						
n	24	27	24	26	25	24
mean	679	1220	2272	2887	1875	1844
SD	320	602	1075	924	944	785
Treatment 3&4						
n	50	54	54	46	52	44
mean	627	765	1835	2059	1774	1844
SD	351	347	950	1016	958	905
			Weeding labour (hours ha⁻¹)			
Treatment 1						
n	25	27	22	23	26	25
mean	86	62	113	118	129	53
SD	44	33	36	26	58	32
Treatment 2						
n	24	27	24	26	25	27
mean	73	61	113	123	137	50
SD	34	34	36	43	90	31
Treatment 3&4						
n	50	54	54	46	52	52
mean	75	80	105	132	137	49
SD	33	43	38	44	88	26

were not significant. The effects appeared to be greater in the comparison of T3&4 with T1 than in the comparison of T2 with T1.

That some VCRs were statistically different from 1.0 does not necessarily prove that a treatment is economically superior. The estimated significance levels might be due to a few extreme values, unrepresentative of most of the distribution. It is also possible that the means do not account for the risks involved in new practices if the variability in net revenues differs among techniques.

Plotting the distributions of net revenues for each farmer allows a view of extreme values in the distribution, and also shows if the difference between

Table 9. *Value:cost ratios*

	1982		1983			
	Sadeize Koira	Gobery	Sadeize Koira	Samari	Gobery	Fabidji
			Economic prices			
Treatment2:Treatment 1						
valid n	24	27	22	23	24	20
mean	0.66**	1.33	1.40*	1.44*	1.76***	0.66
SE	0.15	0.20	0.23	0.22	0.25	0.23
n>1	7	14	14	17	19	7
Treatment 3&4:Treatment 1						
valid n	25	27	21	23	26	19
mean	0.93	0.82	1.65***	0.89	1.99***	0.40**
SE	0.16	0.17	0.21	0.26	0.28	0.22
n>1	11	11	17	10	20	4
			Official prices			
Treatment 2:Treatment 1						
valid n	24	27	22	23	24	20
mean	1.56	3.17***	3.46***	3.48***	4.40***	1.47
SE	0.36	0.47	0.58	0.54	0.63	0.62
n>1	13	21	18	20	20	7
Treatment 3&4:Treatment 1						
valid n	25	27	21	23	26	19
mean	2.14***	1.84**	3.87***	2.22**	4.89***	0.86
SE	0.38	0.39	0.50	0.63	0.68	0.53
n>1	18	20	19	14	23	10

***, **, and * denote significance at $P<0.01$, 0.05 and 0.1, respectively. The null hypothesis is that the mean value:cost ratio is equal to 1.0.

two treatments' net revenues is always positive. If it is, then one treatment is said to dominate the other (Anderson *et al.*, 1977), even if the treatment means are not different or if one treatment is more variable than the other. The difference between net revenues in T3&4 and T1 at economic prices is shown in Fig. 1. The only obvious extreme values are at Samari (positive), and at Gobery (1983, negative). Therefore, any statistically significant treatment effects on the VCRs are probably not due to extremely high or low values. No distribution is always positive, but those from Gobery and Samari in 1983 are mainly so. (A plot of the data from T2 and T1 gave similar results, not shown.)

DISCUSSION

Establishment and replanting

Crop establishment was reasonably good in five of the experiments. Where it was bad, there had been an extended dry period after planting, causing poor growth and necessitating replantings. Where the means were high, the distributions were negatively skewed; outlying low values were sometimes the result of flooding or of wind damage.

There were no clear effects of cultivar, fertilizer or farmer (block) on establishment. Cultivar had a significant and negative effect ($P<0.01$) in only one

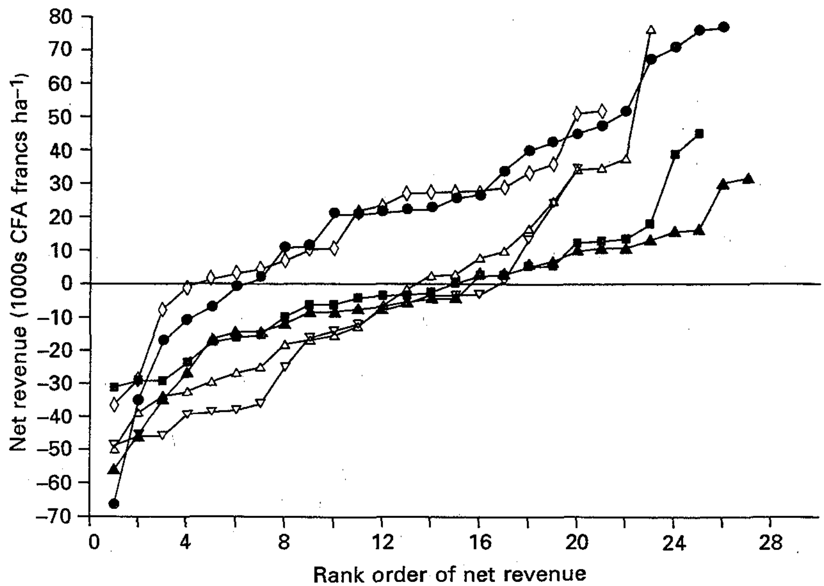

Fig. 1. The difference in net revenue between Treatment 3&4 and Treatment 1 at economic prices for the different sites and seasons (■ Sadeize Koira 1982, ▲ Gobery 1982, ◇ Sadeize Koira 1983, △ Samari 1983, ● Gobery 1983, ▽ Fabidji 1983).

village in 1983, and a positive effect ($P<0.05$) once in 1982. Improved cultivars, selected from local parents, did not establish very differently from farmers' cultivars, and did not usually require more replanting. Maintaining a significant proportion of local genes in improved cultivars may have avoided the establishment problems encountered with exotic lines of millet in Burkina Faso.

The contribution of fertilizer use to crop establishment concerned only the effect of phosphorus, because the nitrogen treatment was applied after crop establishment. The absence of a phosphorus effect in 1982 may be related to the low rainfall in that year; the effect was strongly significant only once ($P<0.01$) in 1983.

Farmer (block) effects were significant, suggesting that crop establishment might be linked to farmer practices independent of cultivar and fertility. In the regression analysis, the one practice clearly identified as causing poor establishment was a delay from the day of the first rains to planting, but this variable was significantly negative ($P<0.01$) in only one village. This inconclusive finding is at least partly due to the small variation in planting delay; in essence, farmers know that it is useless to plant more than four or five days after a heavy rain. Most of the unexplained variation in establishment is probably caused by unmeasured variation in soil moisture at the plot level, associated with differences in early-season rainfall across short distances.

Soil variables rarely affected establishment, because of the poor overall soil fertility of the sites. The negative effects of clay content and of organic matter at Fabidji in 1983 were probably due to the location of some plots on the east side of the village which received less rain than the west. Those plots were in a valley with heavier soils than those of the plateau to the east of the village, so that soil clay content was confounded with low rainfall in the regression analysis.

Because rains are highly variable early in the season, rain sufficient for emergence is often not followed by rain for further crop development, thus necessitating replanting. At least 10% of the plots were replanted in every village, but the number of plots replanted was not usually affected by cultivar or fertility. As fertilizer improved crop establishment in some instances, larger doses of fertilizer may reasonably be expected to reduce the need for replanting in these infertile soils.

Yield loss factors

The incidence of downy mildew, striga and ear-head caterpillar was negligible in both local and improved cultivars. The incidence of chibras and stemborers was much higher, with evidence of reduced chibras infestation in the improved cultivar. The low incidence of most pests suggests that local cultivars might be important sources of tolerance or resistance in breeding programmes. It would be valuable to continue these experiments to test this hypothesis further.

The exception to this generalization was chibras incidence, which was significantly higher in the local millets. This indicates that breeders have succeeded in halting and reversing the introgression caused by *Pennisetum americanum* X *P. violaceum* crosses and in producing improved land races with lower incidence of chibras. Chibras in the improved cultivar plots may also be an agronomic, rather than a breeding, problem. Chibras seeds, derived from the shattering of the inflorescences in the previous season, are in the seedbed before planting. Timely weeding, by removing chibras before flowering, will probably reduce its incidence. The large variation between farmers in chibras incidence perhaps reflects a management difference; some farmers remove chibras before it flowers, while others keep it because it provides some grain before harvest in drought years.

There was considerable variation in all variables within farms, between farms in the same village, and between villages and years. Such variability - even when cultivar and fertility level are controlled - is therefore a major problem in choosing trial sites, suggesting that there is value in long-term trials at the same sites in order to measure year effects and year X site interactions in breeding programmes.

Statistical evidence (not reported in detail in this paper) of the yield losses due to these pests was weak. Regression analyses of millet grain yields showed that chibras had a significant ($P<0.05$) negative effect in two villages, stemborer in one village, ear-head caterpillar in one village, but downy mildew and striga in none. The maximum statistically significant grain loss was 19% of the mean, caused by chibras at Gobery in 1982. (Controlled experiments have shown that a 1% reduction in chibras incidence increased millet yield by 1% (ICRISAT, 1983a).) Other significant losses were caused by stemborer (13% at

Samari) and chibras (14% at Fabidji). Though the lack of significant losses from pests, diseases and weeds was partly due to the aridity of the test years, it suggests that the yield effects of these pests are small where local cultivars, or introduced cultivars based on local parents, dominate.

Economic analysis

Economic analysis of the experiments emphasized four questions: the effects of government price policies, the cultivar X fertility interaction, the fertility X weeding labour interaction, and the possible consequences of variability. At subsidized official prices, the use of fertilizers on the local cultivar was profitable for about 71% of farmers, giving a probability of financial loss of less than 30%. At economic prices, which did not include fertilizer subsidies, using fertilizers on local cultivars of millet was profitable for about 56% of the samples. The net effect of the fertilizer price policy would be to encourage fertilizer use and to transfer income from government to farmers via the fertilizer subsidy.

Fertilizers sometimes gave better yields with improved cultivars than with local ones, but in this case the effect was inconsistent and of little economic importance. However, a significant cultivar effect without fertilizer was found by Ly *et al.* (1986) on Nigerian farms. The number of farmers who would have profited from fertilizer use was about the same for improved and local cultivars. The limited response of the introduced cultivars to fertilizer was partly due to their inferior straw yields. Straw yields of the improved cultivars were roughly 15% less than those of the local millet, so this result is an argument for including straw yield as a criterion in screening programmes.

The hypothesis that fertilizers increase the need for labour, by stimulating weed growth, was rejected as there were no significant treatment effects on the labour used for weeding. This conclusion must be qualified somewhat, because the relatively small, grouped plots may have caused bias in the estimation of labour times which would disappear with dispersed field scale plots.

The plot of the differences in net revenues between T3&4 and T1 demonstrated that the greater mean of T3&4 was not due to a small number of outliers and confirmed the superiority of T3&4 over much of the distribution. (A similar result was seen in the plot of T2 and T1.) Results of the budgetary and the graphic analysis prove that poor returns from the improved treatments are the main constraints to their extension, and that high variability is only a secondary consideration.

The lack of yield of cowpea grain and hay in the intercropping treatment suggests that it should not be recommended to farmers, especially if there is a cash cost for cowpea seed. The result might be different in wetter cropping seasons, but the failure of T4 suggests that it is unacceptably risky in such arid areas.

The general conclusion is that a modest increase in the returns from millet farming could be achieved with the small applications of fertilizers used in these experiments. The use of improved cultivars of millet would have no consistent or large economic effect. Because the experiments took place in dry years, it is likely that fertilizers would give better returns than this in wetter years, possibly by improving crop establishment, and by a greater positive interaction with cultivar. One cautionary note is that grain prices were exceptionally high in 1982 and 1983; millet prices in Niger in the spring of 1987 were about half those at the time of this study and lower prices would obviously reduce profits from fertilizer use.

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REFERENCES

Anderson, J. R., Dillon, J. L. & Hardaker, B. (1977). *Agricultural Decision Analysis.* Ames, Iowa: Iowa State University Press.

Coleman, Gilroy. (1983). The analysis of memory bias in agricultural labour data collection: A case study of small farms in Nigeria. *Journal of Agricultural Economics* 34:79–86.

ICRISAT (1983a). *Annual Report, 1982.* Patancheru, Andhra Pradesh, India: ICRISAT.

ICRISAT (1983b). *Rapport Annuel de l'ICRISAT Haute Volta, Programme Economie, 1982.* Ouagadougou: ICRISAT.

Kowal, J. M. & Kassam, A. H. (1978). *Agricultural Ecology of Savanna: A Study of West Africa:* Oxford: Clarendon Press.

Ly, S., Deuson, R., Maliki, K., Numa, G., Reddy, C. & Swinton, S. (1986). *Evaluation des essais en milieu reel sur les cultures associees mil-niebe: resultats de la campagne de 1985.* Document No 14F. Niamey, Niger: Institut National de la Recherches Agronomiques du Niger.

Sivakumar, M. V. K., Virmani, S. M. & Reddy, S. J. (1982). *Rainfall Climatology of West Africa: Niger. ICRISAT Information Bulletin No 5.* Hyderabad: ICRISAT.