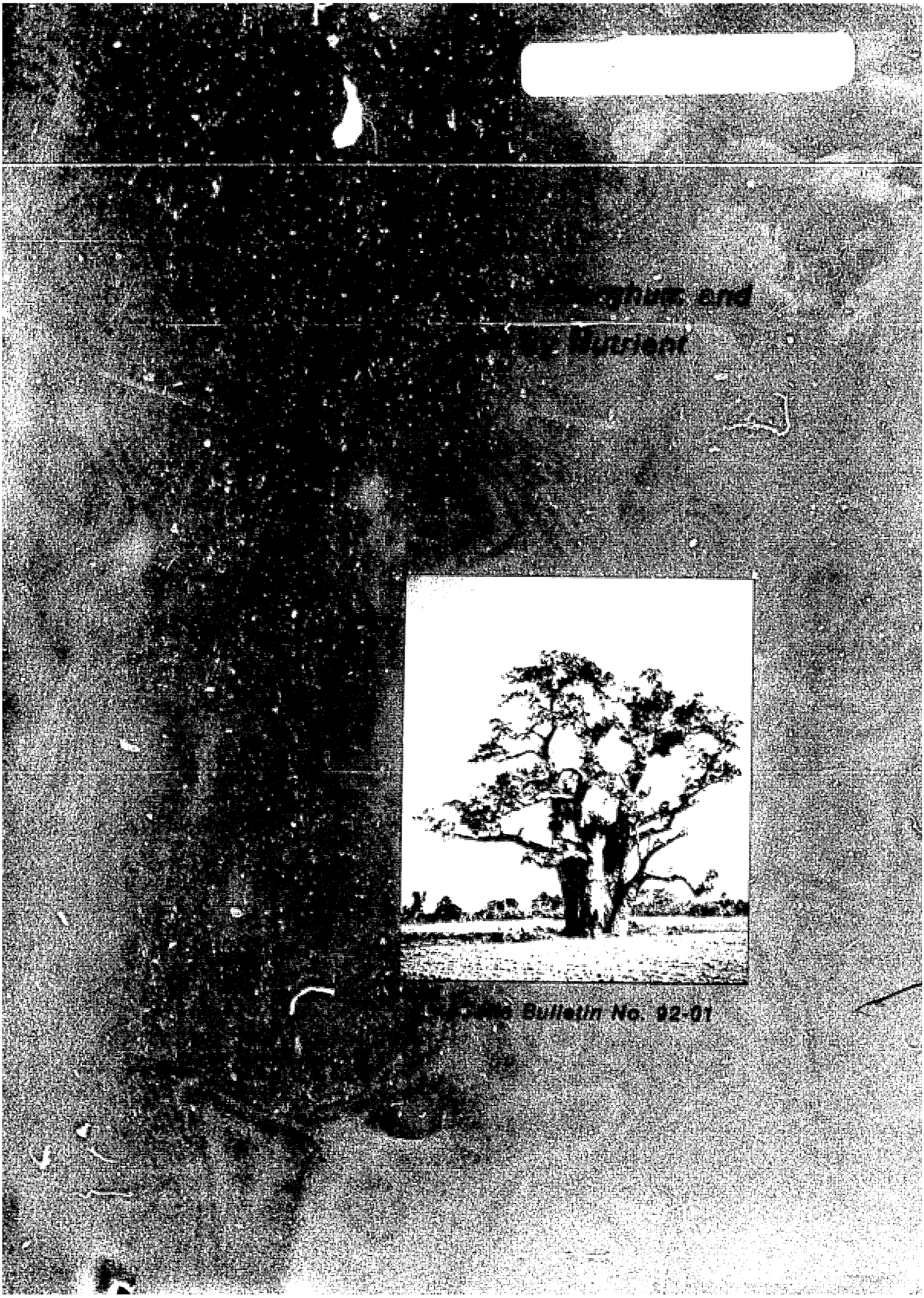

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Soil Water Efficiency of Sorghum and Cowpea as Affected by Nutrient Input and Tillage

A summary of work at the Cinzana Agronomic Research Station, Mali

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Foreword

Texas A&M University (TAMU), as part of the Soil Management Collaborative Research Support Program, initiated collaborative research activities with Mali's L'Institut D'Economie Rurale (IER) in 1983. This research focused on soil management practices that would maximize water-use efficiency for sustainable production of the basic food grains. Management research was designed to address soil differences based on chemical and physical properties and landscape position.

This report contains useful research findings on soil water efficiency of sorghum—*sorghum bicolor* (L.) Moench—and cowpea—*Vigna unguiculata* (L.) Walp—as affected by nutrient inputs and tillage systems. The soil management practices resulting in the highest sustainable yields in this study are appropriate for over 17 million hectares of loam and clay loam soils in the sorghum-producing region of the Sahel in Africa.

The continued support, interest, and encouragement from the IER's Office of the Director-General and from the administrative and technical officers from the USAID Mission in Bamako are gratefully acknowledged. This study was supported in part by the Soil Management CRSP (USAID Grant No. DAN-1311-G-SS-6018-00) administered by AID/S&T/AGR.

Roger G. Hanson, Director
Soil Management CRSP
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Fertilization and Tillage in the Sahel

Summary of Results

Limited information exists on the combined effect of preparing and fertilizing sorghum and cowpea seedbeds in the Sahel. From 1986–1989, a study at the Agronomic Research Station, Cinzana, Mali, compared seedbed preparation techniques—with and without fertilization—for their impact on the growth, yield, and water-use efficiency of grain sorghum and cowpeas; the study was conducted on a loam soil (Plinthaquic Kandustalf).

For both crops, fertilization more consistently enhanced the growth and yield of grain and stover/hay than did tillage. Indeed, fertilization increased yields in every year of the study. Sorghum grain and stover yields increased by up to 64 and 70% respectively; cowpea grain and hay yields increased by up to 59 and 102%.

No tillage and combinations of subsoiling, ridging, and tied ridges were compared. At the beginning of the study, tillage had little effect on growth and yield. By the last year, however, ridging had a major impact on both variables. Compared to no tillage, ridging increased sorghum grain and stover yields by up to 113 and 70%, respectively; cowpea grain and hay yields increased by up to 91 and 102%. Ridging exerted a more consistent effect on sorghum yield than on cowpea yield. Water-use efficiency was similarly affected by fertilization and tillage.

The data show that on fine-textured Alfisols, the yields and water-use efficiency of both crops can be consistently increased by fertilization and tillage. The applicability of these findings will depend on soil type, topography, and economic incentives for

An experimental field at the Cinzana Station, Mali.

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the farmer. In Africa, the findings should be especially relevant on the 17 million hectares of loam and clay soils used for sorghum production.

Soil Deterioration

In the Sahel, increasing population and declining soil fertility threaten long-term food security. Inefficient use of the rainfall contributes significantly to soil deterioration. So too does the removal of crop residues, which are commonly used for fodder and household purposes.

Soil physical properties decline due to inadequate organic input, high soil temperature, raindrop impact, soil exposure, and poor tillage practices. Together, these forces destroy soil structure, thus increasing compaction, runoff, and erosion—and also reducing infiltration and soil water storage. Such problems can be especially acute in Mali, where sorghum is commonly grown in fine-textured soils on river terraces and flood plains.

Low soil fertility (N and P) and soil chemistry problems (low pH and/or Al toxicity) also contribute to the ecosystem's deterioration. In some cases, these fertility and chemistry problems prevent crops from using the limited precipitation.

Research Gaps

Many studies have compared seedbed preparation methods in West Africa; the results are summarized by Nicou (1984) (Table 1). The primary effect of seedbed preparation is to increase infiltration; it has limited effect on the use and conservation of soil water.

In Mali, studies have also been conducted on how mineral fertilization affects corn, millet, and sorghum (Peri, 1974). A summary of results from 1954–1974 shows that regardless of soil, phosphorus limits yield more than any other nutrient—even nitrogen. Potassium had no significant effect on crop yields. The most effective fertilizers contained N and P.

To date, seedbed preparation and fertilization have only been studied separately. The objective of this study was to compare seedbed preparation techniques—with and without fertilization—for their impact on the growth, yield, and water-use efficiency of grain sorghum and cowpeas.

Table 1. Effects of different seedbed preparation techniques on infiltration, utilization, and conservation of soil water (Nicou, 1984).

Parameter influenced by seedbed preparation	Seedbed Preparation Technique		
	Deep Plowing	Open Ridges	Tied Ridges
Infiltration of water into the soil	Effective	Effective	Effective
Utilization of stored soil water	Effective	Not very effective	Not effective
Conservation of infiltrated water	Not effective	Not effective	Not very effective

Experimental Materials and Methods

Research Site

The study was conducted from 1986–1989 at the Agronomic Research Center at Cinzana, Mali, near Ségou in the Ségou region, West Africa. Geographic coordinates are 13°15' north latitude and 5°58' west longitude, between the Niger and Bani rivers (Figure 1). Altitude is 281 meters. The climate is characterized by a strong dry and wet season; 95% of the average annual rainfall of 693 mm falls from May to October. Rainfall was as follows: 1986—633 mm, 1987—565 mm, 1988—701 mm, and 1989—626 mm. Detailed rainfall information is presented in Table 2.

The loam soil (Plinthaquic Kandustalf) in the study is underlain with clay (42–70%) from 10–110 cm (Keita, 1982). Thus, the soil has low permeability. Available phosphorus (1.1–9.5 mg/kg[Bray, No. 1]), nitrogen (0.02–0.04%), and carbon (0.2–0.7%) are also low; pH (5.6–6.6[H_2O]; 4.1–5.1[KCl]) is slightly acid. More detail on soil parameters is provided in Table 3.

Experimental Procedure

Field experiments were conducted in 1986, 1987, 1988, and 1989. Each year, sorghum and cowpea were planted between July 3 and July 22. Sorghum was harvested between October 21 and November 2, cowpea between September 15 and October 15. Harvest index (HI) was determined by dividing the grain yield by the total dry matter produced (grain plus stover/hay). The design of the study was a split plot with two levels of fertilization, six levels of soil preparation, with five replications of each treatment.

The fertilizer levels (main treatments) were as follows:

- F_0—No fertilizer;
- F_1—Fertilizer rate recommended by L'Institut D'Economie Rurale (IER): for sorghum, 100 kg/ha ammonium phosphate (17-46-0) before planting and 50 kg/ha urea (46-0-0) at elongation; for cowpeas, 100 kg/ha ammonium phosphate at planting.

The soil preparation methods were as follows:

- NT—Direct seeding without soil preparation;
- SS—Subsoiling (dry soil);

Table 2. Rainfall during 10- or 11-day periods at Cinzana, Mali, 1986–1989.

Period	1986	1987	1988	1989
18–28 February	4	0	0	0
1–10 March	0	0	0	0
11–20 March	0	0	0	0
21–31 March	0	0	17	0
1–10 April	0	0	1	0
11–20 April	8	0	0	0
21–30 April	0	0	5	0
1–10 May	0	0	0	0
11–20 May	18	0	0	13
21–31 May	31	8	4	10
1–10 June	81	78	8	4
11–20 June	49	29	10	28
21–30 June	15	19	26	84
1–10 July	25	31	76	15
11–20 July	76	5	93	42
21–31 July	29	109	114	71
1–10 August	18	47	66	116
11–20 August	48	60	67	63
21–31 August	29	35	73	72
1–10 September	112	37	83	35
11–20 September	36	17	31	4
21–30 September	37	24	29	1
1–10 October	0	38	0	65
11–20 October	0	31	0	3
21–31 October	11	0	0	0
Total	627	568	703	626

Average rainfall for 1961–1981 was 693 mm.

- SSR—Subsoiling and ridging;
- TR—Tied ridges;
- SSTR—Subsoiling and tied ridges.

Crops planted were as follows:

- Sorghum—Variety CSM 219 from the Malian sorghum collection;
- Cowpea—KN1 from Burkina Faso.

The sorghum was seeded in pockets at 0.80 x 0.40 m spacing and the cowpea at 0.80 x 0.60 m spacing; both were thinned to two plants per pocket approximately three weeks after planting. Crop residues (aboveground biomass) were removed from the field after each harvest. Late in the growing season, root profiles were obtained on selected treatments to further determine the effect of tillage and fertilization on rooting. Samples were obtained with metal cylinders at 10-cm intervals to a depth of 100 cm. Roots were washed from the soil, weighed, dried at 65°C, and weighed again.

To provide information on water-use efficiency, four treatments were selected, and estimates of evapotranspiration (ET) were made using neutron probe measurements (Chopart & Siband, 1988): NTF_0, RF_0, RF_1 and $SSTRF_1$. To provide estimates of soil water changes, aluminum access tubes were installed in the five replications of each treatment to a depth of 270 cm. The plots were bordered to prevent runoff, and deep drainage was not detected. Along with neutron probe data, yield data were also used to estimate water-use efficiency.

Figure 1. Research was conducted at the Cinzana Research Center, Cinzana, Mali, Ségou Region, West Africa.

Table 3. Analysis of soil from the Agronomic Research Center, Cinzana, Mali.

Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Texture	C (%)	N (%)	C/N ratio	Total P (mg/kg)	Available P (mg/kg)	pH (H_2O)	pH (KCl)
0–10	28	28	44	L	0.3	0.02	15.0	270	3.2	6.4	5.1
10–20	55	23	22	Cl	0.7	0.04	17.5	325	9.5	6.1	4.6
20–30	67	16	7	Cl	0.7	0.04	17.5	320	2.5	5.5	4.5
30–40	70	15	15	Cl	0.5	0.02	12.5	270	1.6	6.6	4.6
40–50	72	13	15	Cl	0.3	0.02	15.0	230	9.14	5.8	4.6
50–60	68	13	19	Cl	0.2	0.03	6.6	260	1.3	5.7	4.6
60–70	70	7	23	Cl						5.6	4.2
70–80	46	11	43	Cl						5.6	4.1
80–90	45	11	44	Cl						5.7	4.3
90–100	42	8	50	Scl						5.9	6.0
100–110	45	9	46	Scl						4.2	4.5

Results and Discussion

Sorghum

Plant Populations and Rooting

Sorghum plants emerged in 27,000 to 30,000 pockets per hectare. The crop was thinned to two plants per pocket approximately three weeks after emergence. Fertilization and tillage treatments did not affect the emergence from each pocket. At harvest, the population ranged from 50,000 to 84,000 plants per hectare. Treatments that were fertilized and ridged had significantly more plants than other tillage treatments.

Root weights from core samples show differences due to treatment (Figure 2). Regardless of tillage treatment, fertilization increased the root weight to 100 cm by 0.7–1.1 grams per core. Ridging increased root weight up to 2 grams per profile. The addition of subsoiling to the ridging treatment did not affect the root weight.

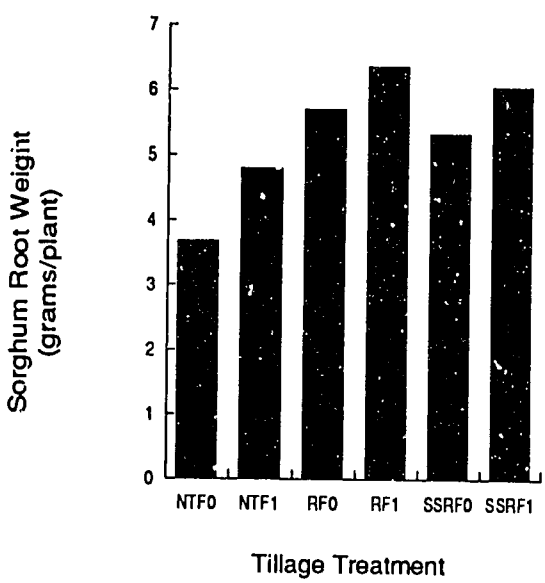

Figure 2. Effect of fertilization and tillage on sorghum root weights at Cinzana, Mali, 1988.

Yields and Harvest Index

Sorghum yield data are presented in Appendices I and II and in Figures 3 and 4. Fertilizer and tillage did not interact to affect yields of either grain or stover during any year (Appendix I). Therefore, only the independent effects of fertilization and tillage are presented. For all four years, fertilization increased yields more significantly than did tillage. Grain and stover yields were increased 800 and 1400 kg/ha, respectively. Increases due to fertilization ranged from 42 to 64% for grain and 31 to 70% for stover.

Responses to tillage were more erratic than to fertilizer. During the first year, tillage produced no trend in either grain or stover yields. As the study progressed, however, the effect of ridging on both grain and stover yields became more pronounced: grain yields were increased over 1100 kg/ha and stover yields over 3000 kg/ha. Subsoiling alone tended to decrease yields with time. No explanation can be given for this trend. Increases due to tillage ranged from 22 to 113% for grain and 31 to 70% for stover. Due to the importance of stover in the Sahel, yield increases are very important.

HI data are presented in Appendix II and Figure 5. HI ranged from 0.14 to 0.31. These values are much lower than those reported by Unger (1991). This discrepancy is not surprising because U.S. sorghum is bred for a short stalk to facilitate harvesting, while African sorghum has a tall stalk because of the stover's value. Fertilization increased HI every year. With the exception of 1989, these increases were significant, indicating that fertilization raised the proportion of dry matter in the grain. Tillage effects were more erratic. In 1986 and 1988, the NT and the SS treatments had the highest harvest index, while in 1987 and 1989, the reverse was true. Thus, tillage produced no harvest-index trend.

Results and Discussion

Water-use Efficiency

Data for four treatments in 1986, 1987, and 1989 are presented in Figure 6. Due to excessive rainfall, it was not possible to obtain estimates of ET and water-use efficiency in 1988. For both grain and stover, subsoiling plus tied ridges with fertilizer ($SSTRF_1$) produced the highest yields and water-use efficiency in all years. The effects of ridging and fertilization changed from one year to another. In 1986, fertilization of similar tillage treatments increased yields 48%. Tillage was effective in 1987 and 1989: water-use efficiency increased up to 200% as compared to the check with no soil preparation and the same level of fertilization. During these years, increased fertilization had little effect on water-use efficiency. For sorghum grown on these soils, the limited data

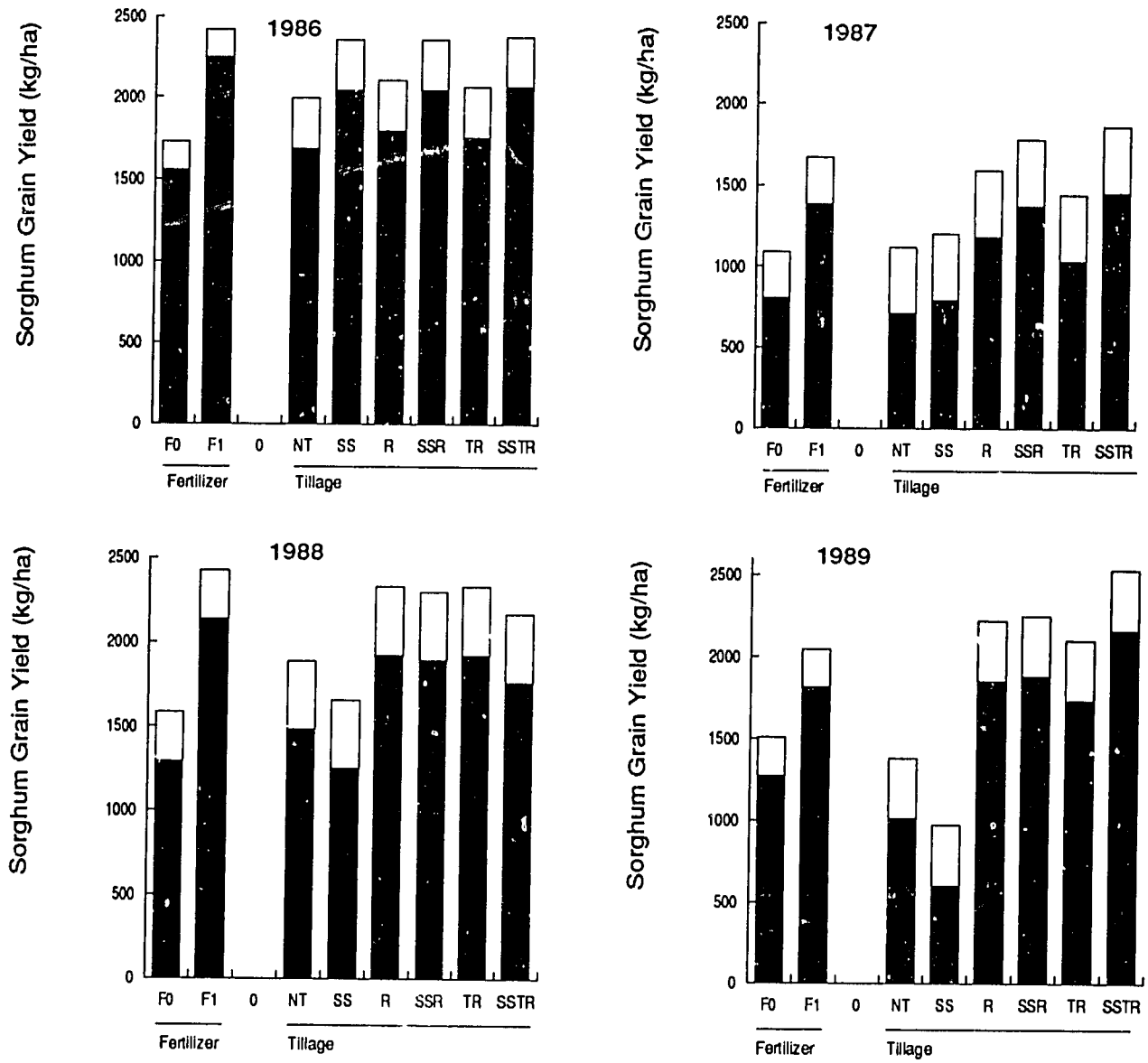

Figure 3. Effect of fertilization and tillage on sorghum grain yields at Cinzana, Mali, 1986–1989. Tops of columns indicate LSD (P = 0.05). F0 = no fertilizer, F1 = recommended fertilizer rate (see above); NT = direct seeding without soil preparation; SS = subsoiling; R = ridging; SSR = subsoiling and ridging; TR = tied ridges; SSTR = subsoiling and tied ridges.

indicate that, in most years, tillage increases water-use efficiency more effectively than fertilization. However, as previously indicated, fertilization was more consistent than tillage in increasing yields in the entire study, thus suggesting that the limited data may not be representative of all the sorghum treatments.

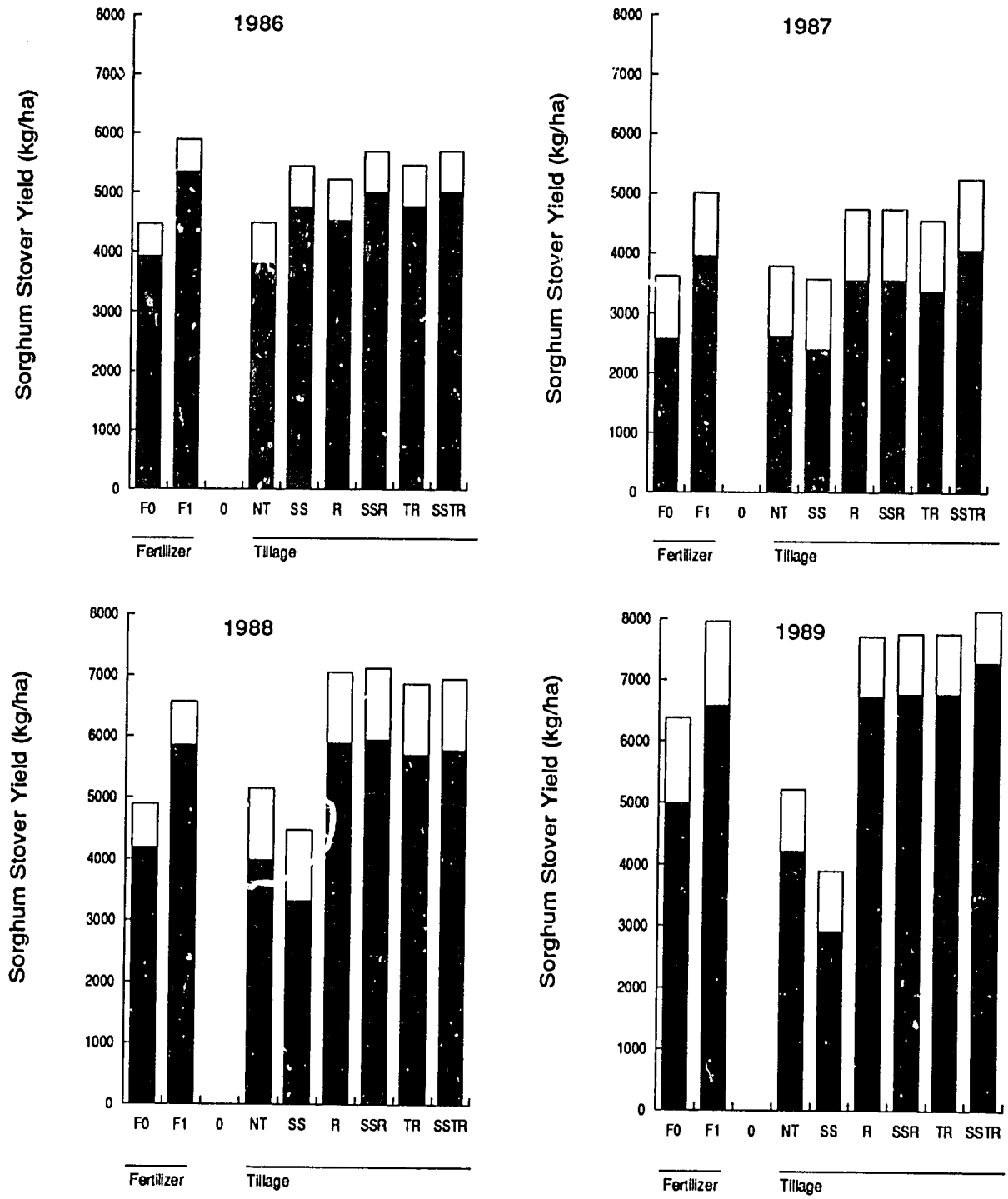

Figure 4. Effect of fertilization and tillage on sorghum stover yields at Cinzana, Mali, 1986–1989. Tops of columns indicate LSD (P = 0.05). F0 = no fertilizer, F1 = recommended fertilizer rate (see above); NT = direct seeding without soil preparation; SS = subsoiling; R = ridging; SSR = subsoiling and ridging; TR = tied ridges; SSTR = subsoiling and tied ridges.

Cowpea

Plant Populations and Rooting

Cowpea emerged in 22,000 to 28,000 pockets per hectare. Pocket emergence was not affected by the different treatments. However, tillage had a significant effect on the plants present at thinning. Treatments without ridging had approximately 44,000 plants per hectare, compared to 52,000 per hectare in the ridged plots. Fertilization had no effect on plant populations.

Root-weight data are presented in Figure 7. Where no fertilizer was applied, root weights

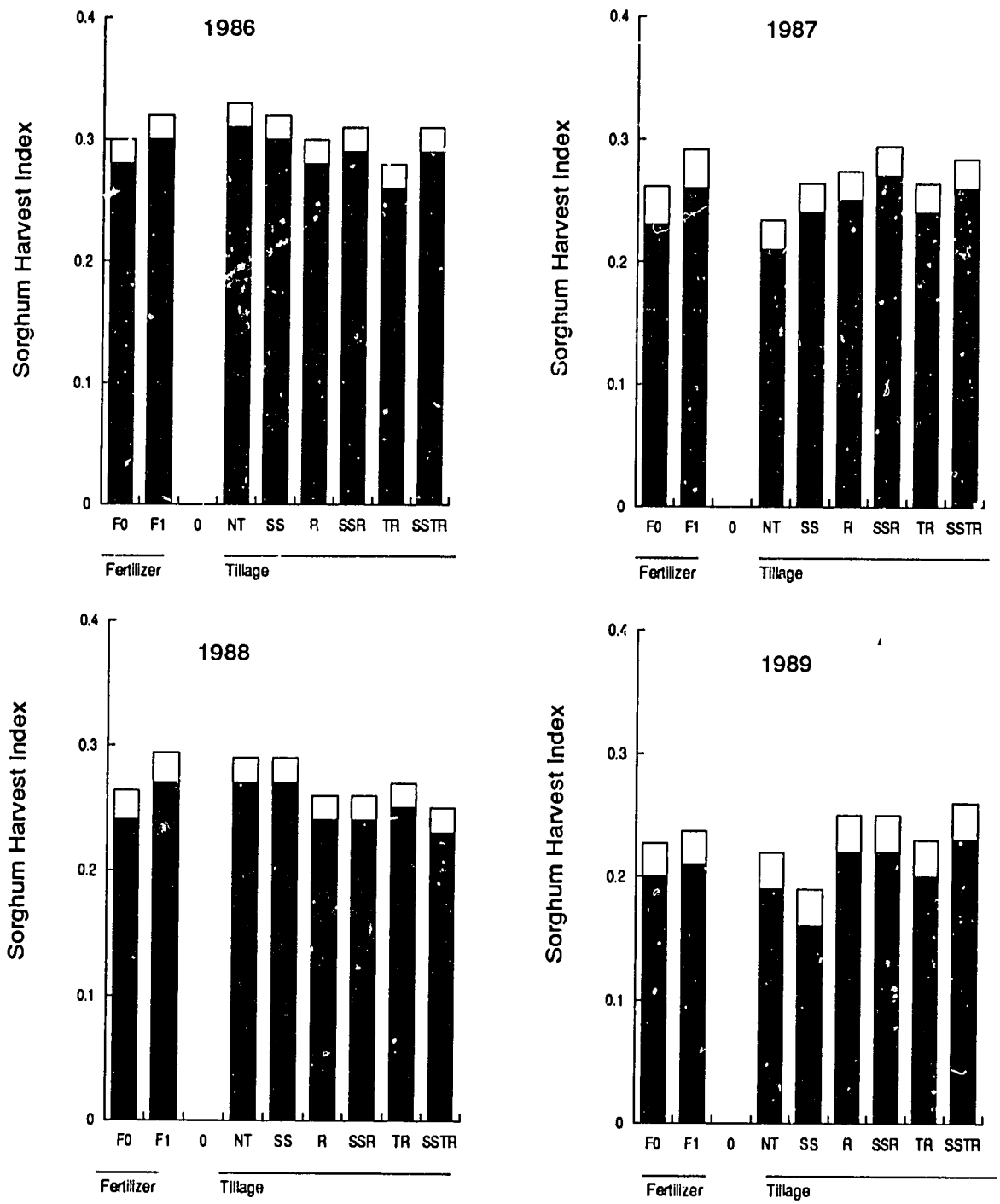

Figure 5. Effect of fertilization and tillage on sorghum harvest index at Cinzana, Mali, 1986–1989. Tops of columns indicate LSD (P = 0.05).

differed little. Where fertilizer was applied, the NT and SSR treatments had increased rooting, while the R treatment did not. Fertilizer and tillage treatments had less effect on cowpea rooting than on sorghum rooting (Figure 2).

Yields and Harvest Index

Detailed yield data are presented in Appendix III, and a summary of the data appears in Figures 8 and 9. As the LSD values indicate, cowpea data varied much more than grain sorghum data (Figures 3 and 4). Fertilization significantly increased both grain and yield regardless of the tillage treatment. Grain yields increased from 141 to 379 kg/ha and hay yields from 527 to 1013 kg/ha. Increases due to fertilization ranged from 41 to 59% for grain and 11 to 102% for hay.

Tillage results varied. Subsoiling alone did not increase yield. Indeed, for unfertilized treatments, the average grain yield with subsoiling was lower than for the no-tillage treatment (231 vs 412 kg/ha). On the other hand, all treatments with ridging (R) had higher yields than the NT and SS treatments. In 1988, yields from R were significantly higher than from NT alone; in 1989, yields from R were higher than from both NT and SS only treatments. R increased hay yields as follows: in 1987 and 1989, treatments with R were significantly higher than those with NT and SS; in 1988, they were higher than those with SS. R increases exceeded NT increases by a range of 21 to 91% for grain and 11 to 102% for hay. As with sorghum, the tillage treatment which had a major impact on yield was ridging.

Cowpea HI (Figure 10) varied much more than that of sorghum (Figure 5), ranging from 0.15 to 0.48. Because of the poor hay yield in 1989, indices were much higher than in 1987 and 1988.

Water-use Efficiency

Due to excessive rain in 1988, it was not possible to estimate water-use efficiency. Data for 1989 are

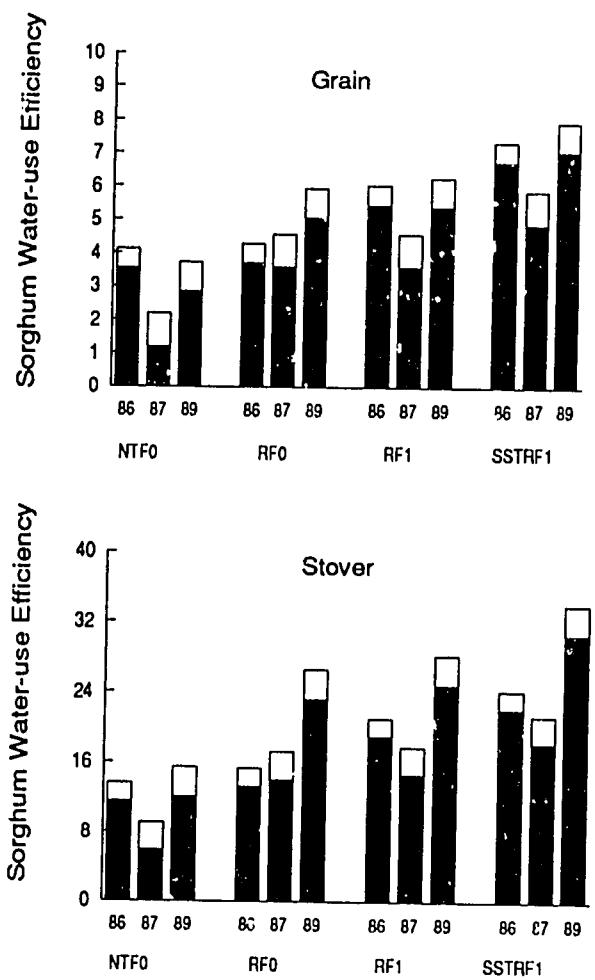

Figure 6. Effect of fertilization and tillage on sorghum grain and stover water-use efficiency at Cinzana, Mali, 1986–1989. Tops of columns indicate LSD (P = 0.05).

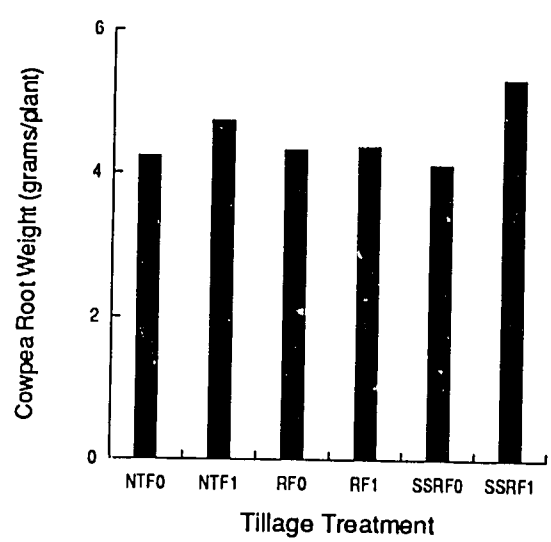

Figure 7. Effect of fertilization and tillage on cowpea root weights at Cinzana, Mali, 1986–1989.

presented in Figure 11. Water-use efficiency of the RF_0 treatment was 82% greater than the NTF_0 treatment. Fertilization (RF_0 vs RF_1) further increased water-use efficiency only 17%. Water-use efficiency was increased similarly by both ridging (50% lower for NTF_0 than for RF_0) and fertilization (53% lower for RF_0 than for RF_1). The $SSTRF_1$ treatment exceeded RF_1 in grain production by 17%, but not in hay production (22% decrease). As with sorghum, results from these four treatments may not reflect the water-use efficiency of the other eight treatments.

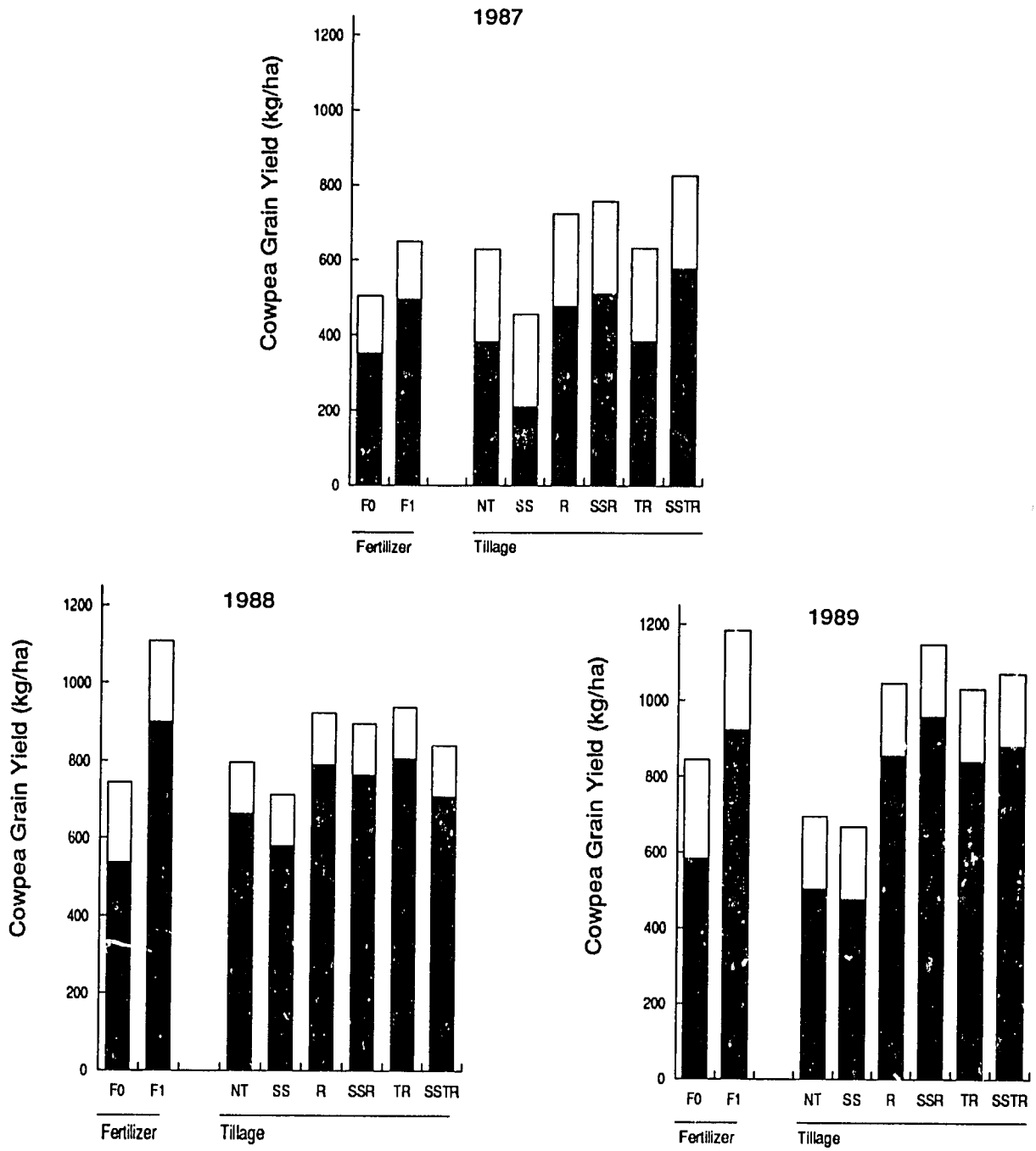

Figure 8. Effect of fertilization and tillage on cowpea grain yields at Cinzana, Mali, 1987–1989. Tops of columns indicate LSD (P = 0.05).

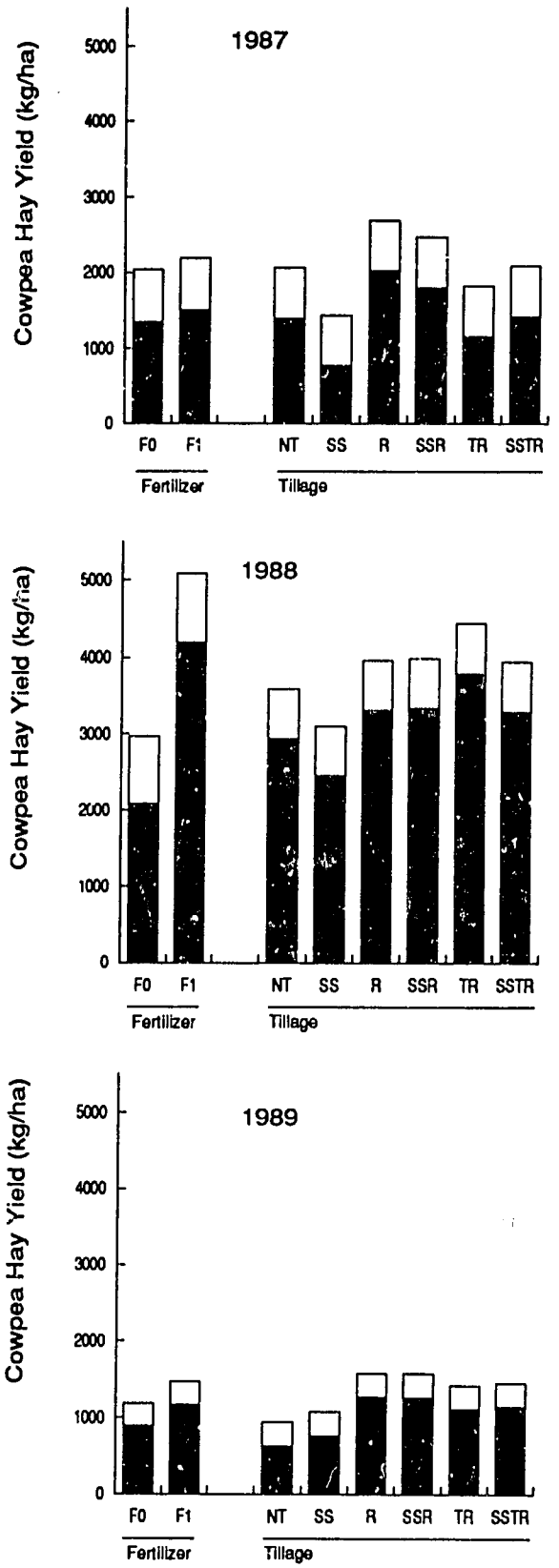

Figure 9. Effect of fertilization and tillage on cowpea fodder yields at Cinzana, Mali, 1987–1989. Tops of columns indicate LSD (P = 0.05).

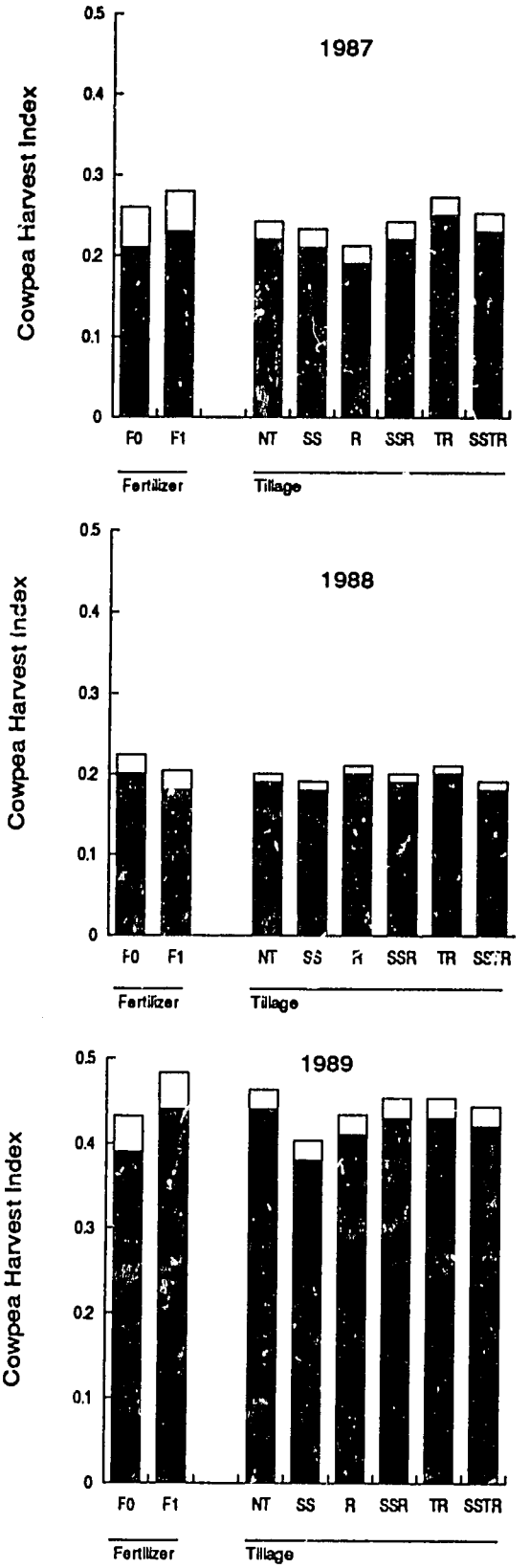

Figure 10. Effect of fertilization and tillage on cowpea harvest at Cinzana, Mali, 1987–1989. Tops of columns indicate LSD (P = 0.05).

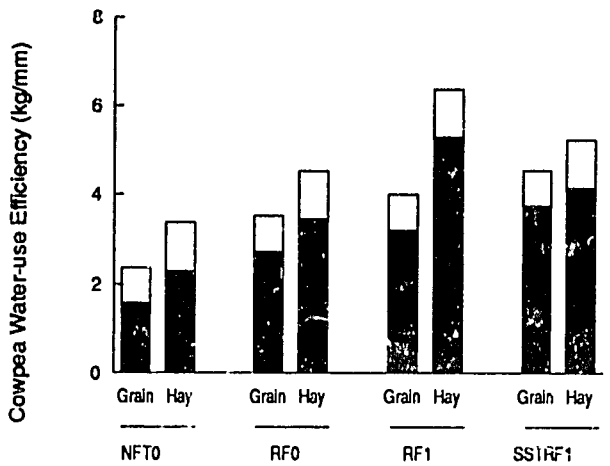

Figure 11. Effect of fertilization and tillage on cowpea grain and hay water-use efficiency at Cinzana, Mali during 1988. Tops of columns indicate LSD (P = 0.05).

Conclusions and Management Implications

Conclusions

Sorghum and cowpea were grown in rotation under fertilization and various tillage treatments. There were no interactions between the fertilizer and tillage treatments. Even though the soil had been fallowed for a number of years prior to the study, fertilization consistently increased the yields of both sorghum and cowpeas, an indication that the soil is inherently infertile. The tillage practice that had a major impact on sorghum and cowpea was ridging (Figure 12). Sorghum root weights were higher with ridging than with other tillage treatments. The corresponding data on cowpea were more variable.

As one might expect, yields followed similar trends. Both ridging and fertilization significantly increased sorghum and cowpea grain and stover/hay yields. Even though fertilization produced more consistent increases, ridging may be more feasible because of the high cost of chemical fertilizers.

Although water-use efficiency data were limited, the trends resemble those mentioned above. Ridging and fertilization increased the water-use efficiency of both sorghum and cowpea fodder and grain. The water-use efficiency of cowpea grain and hay was only 53 to 60% of sorghum grain and 14 to 19% of sorghum stover.

Figure 12. On the fine-textured, kaolinitic Alfisols at the Cinzana Station—without crop residue—sorghum grew better in the ridged plot (left) than in the no-till plot.

Management Implications

To increase productivity in the Sahel, water must be used more efficiently. This study indicates that—on loam and clay soils—both fertilization and ridging can help to provide that kind of efficiency for sorghum and cowpea production. Indeed, such methods can increase grain and stover/hay yields by 150 to 200%. If such practices were adapted to family farms across the 17 million hectares of loam and clay soil in sorghum-producing Africa, they could help the Sahel become self-sufficient producers of food grain.

To improve nutrient-use efficiency, TropSoils and IER researchers are conducting further studies in Mali to evaluate the effectiveness of green-manure crops in recycling mineral nutrients and improving soil physical properties.

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Appendix I

Statistical data for sorghum and cowpea at Cinzana, Mali, 1986.

Crop	Source	df	Grain Yield 1986	Grain Yield 1987	Grain Yield 1988	Grain Yield 1989	Grain Yield 1986	Grain Yield 1987	Grain Yield 1988	Grain Yield 1989
Sorghum	Fertilizer (F)	1	**	**	**	**	**	**	**	**
	Tillage (T)	5	ns	**	*	**	ns	**	**	**
	FXT	5	ns	ns	ns	ns	ns	ns	ns	ns
Cowpeas	Fertilizer (F)	1		ns	**	*		ns	**	ns
	Tillage (T)	5		ns	*	**		**	*	**
	FXT	5		ns	ns	ns		ns	ns	ns

** and * indicate significance at .01 and .05 probability levels, respectively.

Appendix II

Sorghum yield and harvest index data at Cinzana, Mali, 1986–1989.

Year/treatment	Grain Yield (mg ha^{-1})			Stover Yield (mg ha^{-1})			Harvest Index		
	F_0	F_1	X	F_0	F_1	X	F_0	F_1	X
1986									
No tillage	1.31	2.05	1.68b*	2.94	4.63	3.79b	0.31	0.31	0.31a
Deep Plowing	1.81	2.27	2.04a	4.33	5.15	4.74	0.29	0.31	0.30a
Ridging	1.45	2.14	1.79b	3.71	5.32	4.52a	0.28	0.29	0.28a
Deep Plowing + Ridging	1.63	2.45	2.04a	4.11	5.87	4.99a	0.28	0.29	0.29a
Tied Ridges	1.58	1.93	1.75b	4.39	5.14	4.76a	0.26	0.27	0.26b
Deep Plowing + Tied Ridges	1.51	2.62	2.06a	4.05	5.95	5.00a	0.27	0.31	0.29a
Mean	1.55b	2.24a	1.89	3.92b	5.34a	4.63	0.28b	0.30a	0.29
1987									
No tillage	0.40	1.02	0.71c	1.61	3.82	2.61ab	0.20	0.21	0.21d
Deep Plowing	0.47	1.11	0.79bc	1.86	2.91	2.39b	0.20	0.28	0.24c
Ridging	1.19	1.18	1.18ab	3.48	3.63	3.55a	0.25	0.25	0.25bc
Deep Plowing + Ridging	0.81	1.93	1.37a	2.34	4.75	3.55a	0.26	0.29	0.27a
Tied Ridges	0.87	1.20	1.03abc	3.11	3.60	3.36ab	0.22	0.25	0.24b
Deep Plowing + Tied Ridges	1.08	1.82	1.45a	3.11	4.98	4.05a	0.25	0.27	0.26ab
Mean	0.80b	1.38a	1.09	2.57	3.95	3.30ab	0.23b	0.26a	0.24
1988									
No tillage	1.02	1.94	1.48b	3.38	4.57	3.98b	0.23	0.30	0.27a
Deep Plowing	0.74	1.86	1.25b	2.32	4.30	3.31b	0.24	0.30	0.27a
Ridging	1.48	2.37	1.92a	5.04	6.72	5.88a	0.23	0.26	0.24bc
Deep Plowing + Ridging	1.53	2.26	1.89a	5.30	6.59	5.94	0.22	0.26	0.24bc
Tied Ridges	1.68	2.16	1.92a	4.80	6.84	5.69a	0.26	0.25	0.25b
Deep Plowing + Tied Ridges	1.32	2.20	1.76ab	4.26	7.27	5.77a	0.24	0.23	0.23c
Mean	1.29b	2.13a	1.71	4.18b	5.64a	5.09	0.24b	0.27a	0.25
1989									
No tillage	0.86	1.17	1.01c	3.72	4.69	4.21b	0.19	0.20	0.19b
Deep Plowing	0.31	0.90	0.60d	1.91	3.89	2.90b	0.14	0.19	0.16c
Ridging	1.79	1.92	1.85ab	6.47	6.95	6.71a	0.22	0.22	0.22ab
Deep Plowing + Ridging	1.51	2.25	1.88ab	5.60	7.93	6.76a	0.21	0.22	0.22ab
Tied Ridges	1.46	2.00	1.73b	6.31	7.21	6.76a	0.19	0.22	0.20b
Deep Plowing + Tied Ridges	1.72	2.61	2.16a	5.87	8.70	7.28a	0.23	0.23	0.23a
Mean	1.27b	1.81a	1.54	4.98b	6.56a	5.77	0.20	0.21	0.20

* Values with different letters differ at the 0.05 level of probability.

Appendix III

Cowpea yield and harvest index data at Cinzana, Mali, 1987–1989.

	Grain Yield (mg ha^{-1})			Hay Yield (mg ha^{-1})			Harvest Index		
Year/treatment	F_0	F_1	X	F_0	F_1	X	F_0	F_1	X
1987									
No Tillage	378	383	381	1724	1041	1383abc*	0.18	0.27	0.22
Deep Plowing	155	262	209	567	949	758c	0.21	0.22	0.21
Ridging	373	576	475	1622	2397	2010a	0.19	0.19	0.19
Deep Plowing + Ridging	383	636	509	1685	1893	1789ab	0.19	0.25	0.22
Tied Ridges	363	402	383	1351	939	1145bc	0.21	0.30	0.25
Deep Plowing + Tied Ridges	446	707	577	1070	1748	1409abc	0.29	0.18	0.23
Mean	350	494	422	1337	1495	1416	0.21	0.23	0.22
1988									
No Tillage	449	874	662ab	1813	4041	2927ab	0.20	0.18	0.19
Deep Plowing	216	942	579b	1247	3643	2445b	0.15	0.21	0.18
Ridging	737	841	789a	2673	3934	3304a	0.22	0.18	0.20
Deep Plowing + Ridging	596	927	762a	2154	4500a	3327a	0.22	0.17	0.19
Tied Ridges	645	963	804a	2212	4756	3784a	0.23	0.17	0.20
Deep Plowing + Tied Ridges	570	841	706ab	2319	4247	3283a	0.20	0.17	0.18
Mean	536b	898a	717	2070b	4187a	3128	0.20	0.18	0.19
1989									
No Tillage	410	593	502b	600	636	618b	0.41	0.48	0.44
Deep Plowing	323	627	475b	621	882	752b	0.34	0.42	0.38
Ridging	796	911	854a	1010	1508	1259a	0.44	0.38	0.41
Deep Plowing + Ridging	732	1181	957a	1164	1344	1254a	0.39	0.47	0.43
Tied Ridges	682	993	838a	964	1231	1098a	0.41	0.45	0.43
Deep Plowing + Tied Ridges	542	1215	879a	923	1344	1134a	0.37	0.47	0.42
Mean	581b	920a	751	880	1158	1019	0.39	0.44	0.42

* Values with different letters differ at the 0.05 level of probability.