145 Management Options for Intensifying Millet-Based Crop Production Systems on Sandy Soils in the Sahel

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Introduction

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is a major staple crop grown on 14 million ha of the semi-arid Sahelian and Sudanian ecological zones. The crop is generally grown in association with cowpea [*Vigna unguiculata* (L.) Walp] by subsistence farmers using manual labor for all cropping operations. Chemical fertilizers are rarely applied. Cash inputs for crop husbandry are limited to the occasional hiring of labor. Labor shortages are most severe for weeding operations. The millet-growing area in Niger has doubled to 3.2 million ha during the last 25 years, while average grain yields have dropped from 0.48 Mg/ha to 0.30 Mg/ha (Anonymous, 1987). The decline in yields suggests that: production has expanded into increasingly marginal areas, fallow periods have become too short to allow natural restoration of fertility, and technical change has not yet had an impact on food production (Spencer, 1985). In the future, it will be necessary for production increases to come from increased yields. Experience at the ICRISAT Sahelian Center (ISC) leads us to believe yield increases are technically feasible if the principal limiting factors—inherently low soil fertility, limited and untimely cultural practices, and the occurrence of drought periods—are overcome (Fussell et al., 1987; Klaij and Hoogmoed, 1987).

The paper focuses on field experiments at ISC evaluating the effects of various soil and crop management practices on the plant establishment, yield, and water use of pearl millet.

The Soil Environment

The predominant soil series at the ISC are classified as a Psammentic Paleustalf (West et al., 1984). The sand content is around 900 g/kg, of which 85% fall within Chepil's classification (quoted by Zachar, 1982) of particles with a very high (0.1-0.15 mm) to high (0.05-0.1 mm and 0.15-0.50 mm) potential for wind erodibility. The soil surface is generally flat and smooth with a negligible surface storage capacity. A weak crust may be present. Soil bulk densities range from 1.40 to 1.70 Mg/m corresponding to a porosity of 36% to 43%. Densities at the higher end of this range may hamper root development. These soils are poorly buffered, having cation exchange capacities of about 0.013 mol/kg and a pH(KCl) of 4.5 to 5.5. Organic matter (OM) levels are very low, in the order of 3 g/kg. The available soil water at field capacity is 70 to 100 g/kg. During the seedling establishment period, soil temperatures at 5-cm depth reach 42°C on a sunny day following rain. The average onset of the rains at ISC is 12 June, the average annual rainfall is 560 mm, and the average length of the growing season is 94 days (Sivakumar, 1987).

The Effects of Tillage

On the sandy soils at the ISC, reductions in bulk density and soil surface modifications resulting from tillage do not have an important impact on infiltration. These soils have weak crusts that generally do not reduce infiltration rates. Rainfall simulations on 1.5 x 1.5 m plots (3-4% slope) demonstrated sustained infiltration rates of 100 mm/hour for over 2 hours. Actual runoff on untilled plots cropped with millet (6 x 24 m, 3-4% slope) was 1.5% at most from 1984 to 1987.

Reduced bulk density from tillage results in enhanced rooting, greater access to soil water, increased fertilizer uptake, and, therefore, more secure and higher yields (Charreau and Nicou, 1971; Chopart, 1983). These effects are most pronounced in dry years. Modifications in the soil surface such as ridging may reduce soil losses due to wind erosion by as much as 85% (Fryrear, 1984). At the ISC, several tillage methods have been evaluated in combination with other crop-management practices such as the addition of phosphorus fertilizers, maintaining crop residues in the field, and leguminous crop rotations.

Primary Tillage, Fertilization, and Residue Management

Two experiments addressing these issues were conducted at the ISC. In the first, the effects of plowing to a depth of 15 cm, ridging (75 cm between ridges, ridge height 15 cm) without other primary tillage, "sandfighting" (increasing the surface roughness by creating small depressions and clods), and a zero-tillage treatment were compared for millet production over a 2-year period. In the second, concurrent experiment, that was repeated over 3 years, the "sandfighting" treatment was dropped and the other tillage treatments maintained. In this case, crop residues were either maintained or removed. In both cases, these treatments were compared with or without the addition of chemical fertilizers; 17 kg P/ha pre-sowing and a split application of 40 kg N/ha at 3 and 6 weeks after sowing.

The tillage treatments were carried out at the beginning of the rainy season with the first rainfall exceeding 10 mm. Plowing and ridging with soil water at field capacity reduced soil bulk densities in the 0- to 15-cm layer to 1.22 Mg/m^3, thus increasing porosity to 54%. Compaction due to raindrop impact during the season was low. Penetrometer measurements confirmed the persistence of reduced bulk density throughout the season. Two months after plowing, soil resistance was still 50% lower than in untilled soil. Millet was planted on 13,000 hills/ha in rows 75 cm apart. Crop growth, water use, soil OM, and soil pH were monitored.

Fertilizer use was the most important factor contributing to better stands and yields. In the first experiment, plowing and ridging improved plant stands and yields more when they were combined with fertilizer use. The response to fertilizer was moderate in the absence of primary tillage and on "sandfought" plots (Table 1). Ridging without other primary tillage requires considerably less time and energy than plowing. Ridging also helps to reduce wind erosion by increasing the surface roughness, which lowers wind speeds and traps sand in the furrows, thereby minimizing seedling abrasion and burial.

For the second experiment, stand establishment data are not presented because the millet was grown in a protected area where wind erosion was not a problem. However, due to insect damage to the panicles, only biomass (total dry matter) data will be presented (Table 2). Biomass was increased by 89% with fertilizer use. Mulching, either millet haulms (stalks) (2-4 Mg/ha) left on the surface, or partially incorporated in ridges, or plowed under, increased yields by 54% on unfertilized plots and 12% on fertilized plots. Without fertilizer or crop residues, the effect of primary tillage was moderate, resulting in yield increases of only 11 to 16%. There was a significant tillage x fertilizer x crop residue interaction. When ridging is practiced, residues are concentrated in the ridge. Ridging with crop residues and without added fertilizer depressed yields. When fertilizer was applied, ridging with crop residues enhanced crop yields. Be-

Table 1. Effect of pre-sowing cultivation and fertilization on plant population (in percentage of number of hills survived at harvest) and grain yield, ISC, rainy seasons 1985 and 1986.

Treatment[a]	Stand at harvest			Grain yield		
	F0	F1	Mean	F0	F1	Mean
	%			Mg/ha		
Plowing	68	87	78	0.254	0.681	0.467
Ridging	44	80	62	0.180	0.649	0.414
Sandfighting	31	63	47	0.089	0.352	0.220
Zero-till	42	63	53	0.139	0.402	0.271
SE	±3.3		±2.5	±0.040		±0.034
Mean	46	73		0.165	0.521	
SE	±1.5			±0.015		

[a] F0 = control; F1 = fertilizer added. Split-split-plot replicated 4 times, subsub plot size 30 m^2. Average across 2 years and 3 cultivars.

Table 2. Effect of fertilizer use, pre-sowing cultivation, and use of crop residue, on total dry matter yield of pearl millet, ISC, rainy seasons of 1985, 1986, and 1987.

Treatment[a]	F0			F1		
	R0	R1	Mean	R0	R1	Mean
	Mg/ha					
Plowing	2.46	4.16	3.31	5.48	5.68	5.58
Ridging	1.97	2.80	2.38	4.69	5.86	5.28
Zero-till	2.22	3.27	2.74	4.72	5.43	5.07
Mean[b]	2.21	3.41	2.81	4.96	5.56	5.31

[a] F0 = no fertilizers added; F1 = 17 kg/ha of P fertilizer and 40 kg/ha of N; R0 = crop residue removed; R1 = crop residue left. Split split plot replicated 3 times, subsub plot size 60 m^2. Average across 3 years and 2 cultivars.
[b] SE for comparing means are for: fertilization - 0.223, tillage - 0.108, residue - 0.088, and their interaction - 0.298.

tween 1985 and 1986, mulching increased OM from 2.6 to 2.9 g/kg (SE= ±0.006) while the pH (KCl) increased from 4.98 to 5.16 (SE= ±0.06). It is likely that the beneficial effects of crop residues stem from changes in the soil biological and chemical processes rather than physical ones. Maximum soil temperatures are decreased by only 1 to 2°C with the low levels of mulch present in this experiment. The water use increased in 1986 from 287 mm on the lowest-input plots to 320 mm when the highest levels of inputs were applied. Water use efficiencies were higher in all years with higher levels of inputs, especially fertilizer.

Tillage and Crop Rotation

In another soil management experiment, the effects of tillage executed either at the end of the previous season or at the beginning of the rainy season, were compared with a legume, cowpea, and millet rotation or a continual millet cropping pattern. Seventeen kg/ha of P fertilizer was applied before sowing.

In 1987, the previous sole-cropped cowpea increased the millet grain yields from 0.50 to 0.65 Mg/ha (SE = ±0.03). This effect was more important in the presence of plowing or ridging, with millet yields increasing from 0.48 Mg/ha with the zero-tillage treatment to 0.70 Mg/ha with the ridging and to 0.76 Mg ha-1 with plowing (SE = ±0.03). Whether the primary tillage was carried out at the end of the previous season or at the beginning of the cropping season did not have much effect on millet yields.

The greater effect of cowpea rotation when primary tillage is practiced is not fully understood. Higher cowpea yields for the tillage treatments may be associated with leaving in the soil roots and other residues with their associated nutritive value, especially N in these treatments. Increased rooting associated with lower bulk densities from primary tillage could have also contributed to better utilization of residual fertility from the cowpea crop. Soil chemical analysis of samples taken before and during the experiment is underway.

Conclusion

Primary tillage improves stand establishment and survival. This results in higher yields especially when used in combination with fertilizers. Removal of crop residues depresses yields. Ridging seems to be the most promising technique. It requires less energy than plowing and helps to control wind erosion. Tillage in combination with crop rotation increases millet yields.

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