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Soil management for crop production in the West African Sahel. II. Emergence, establishment, and yield of pearl millet*

M.C. Klaij[a] and W.B. Hoogmoed[b]

[a]*ICRISAT Sahelian Center, Resource Management Program, BP 12404, Niamey, Niger*
[b]*Tillage Laboratory, Wageningen Agricultural University, Diedenweg 20, 6703 GW Wageningen, Netherlands*

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ABSTRACT

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Crop establishment is an important yield factor for pearl millet in the Sahel. Therefore, we conducted a series of experiments to determine the effects of seed size, depth and method of planting, millet variety, pre-sowing tillage, and soil fertilization upon seedling emergence, crop establishment, and yield. All experiments were conducted on a sandy Psammentic Paleustalf in Niger.

For all three millet varieties studied, out of a range of sowing depths from 1 to 7 cm, a sowing depth of 3–5 cm resulted in the highest percentage emergence, the highest above-ground biomass, and most secondary roots. High soil temperatures are common during establishment, typical maximum temperatures at a depth of 1 cm exceed 46 °C. The adverse effects of wind erosion were least when sowing in hills; establishment, crop stand survival, and yield were better under hill planting than drilling seed.

Pre-sowing tillage increased initial stands and their survival, the latter also depending on fertility. Thus, improved crop yields result from better stand survival and higher yields per hill. Fertilizer application of 17 kg ha^{-1} P and 40 kg ha^{-1} of N tripled grain yields. Ridging without prior tillage and plowing increased grain and stover yields two- to three-fold. In combination with fertilizer application, sixfold yield increases were obtained.

If pre-sowing tillage is considered, then, in view of the time limitations, ridging without prior tillage would be preferable to plowing, as it is a much faster operation giving equally good results in terms of crop establishment and yield.

INTRODUCTION

This paper is the second in a series dealing with soil and crop management options for increasing crop production in the Sahelian agro-climatical zone. The first paper described soil parameters of the sandy soil (Psammentic Pa-

Correspondence to: M.C. Klaij, ICRISAT Sahelian Center, BP 12404, Niamey, Niger.

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leustalf) of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Sahelian Center (ISC) near Niamey, Niger (Hoogmoed and Klaij, 1990a). Climatic parameters across Niger were also analyzed. These two parameters have important soil and crop management implications.

Seasonal, high intensity rainfall, high temperatures, and physically and chemically poor soils commonly result in poor crop stands and yield of pearl millet. Early sowing is important as each week of delay in sowing advances the heading date by 1 day, potentially decreasing yields (Kassam, 1976). The method of sowing and seed quality are also important factors (Soman et al., 1987). How these factors interact in affecting stands, and the best tillage and sowing technique depend largely on the soil and location.

Farmers' sowing practices

A study of some of the factors affecting establishment was carried out in the Niamey region in the early season of 1985 (ICRISAT, 1986; Soman et al., 1987). Farmers sow immediately following rain without prior tillage. With a long handled hoe planting holes are made, into which a variable number of 40–300 seeds are deposited (hill). Subsequently, the soil is pushed back and compacted by foot. As a result, sowing depth varies, both within and between fields, ranging from 2 to 8 cm. The number of hills varies from 3500 to 11 000 ha^{-1}. Although standard laboratory germination of the seeds used was good (over 80%), average emergence was only 25%. Low seedling emergence should not be a problem provided the surviving seedlings produce grain. However, a generally dry period followed, and post-emergence death of seedlings reduced otherwise adequate stands. Stands declined on average from 4900 to 2300 hills ha^{-1}, and stand failure was noted in nearly half of the fields studied. This was attributed to high soil temperatures, rather than to low soil water content (ICRISAT, 1986).

Seed factors

Field emergence rates are positively related to seed size (Lawan et al., 1985), but even in the best circumstances on-station seedling emergence rates range typically between 32 and 40% (ICRISAT, 1987). According to Stomph (1990), differences between the emergence rates of different genotypes are easily blurred by variable environmental conditions during the growth cycle, seed processing, and storage of the seed.

Environmental factors

Early storms are often accompanied by strong winds. Wind speeds exceeding 100 km h^{-1} have been recorded at ISC (Sivakumar, 1989). Blowing sand subjects seedlings to abrasion, and often results in their being completely covered by sand, causing serious problems in crop establishment. When there is insufficient crop residue to protect the soil surface, 'emergency tillage' practices must be used to provide protection (Fryrear, 1969). The principle is to create a rough and cloddy soil surface. When such clods are not produced, or easily disintegrate, ridging may be the only effective method of roughening the soil surface (Fryrear, 1969). Wind tunnel studies have shown that under such circumstances, ridges 127–248 mm in height were most effective and reduced soil erosion rates by 85% (Fryrear, 1984). Under moist conditions relatively stable clods can be formed by tillage (Hoogmoed and Klaij, 1990a). An alternative emergency tillage tool used to quickly roughen the surface of sandy soils is called a 'sand fighter'. This consists of an axle, with radial tines, which when pulled over the surface creates small depressions and clods in wet soils. Sand fighting has to be repeated after each rain event (Fryrear, 1969).

Soil compaction

Poor crop performance may also result from poor rooting due to soil compaction, and from reduced rainfall infiltration due to crusting. Remedial mechanical loosening of the soil is then necessary (Charreau and Nicou, 1971; Lal, 1989). Extensive tillage research in semi-arid West Africa indicates the beneficial effect of reduced soil bulk density on root proliferation of groundnut, sorghum, maize and upland rice (Blondel, 1967; Nicou, 1974; Nicou and Charreau, 1985), and even of millet in sandy soils (Chopart and Nicou, 1976). Chopart (1983) reports a doubling of root dry weight of millet in a plowed sandy soil compared with no-till, during the first 50 days. Strong positive correlations between the reduction of soil bulk densities, root growth, and yield have been reported for many crops of the region (Charreau and Nicou, 1971). Millet grain yields are reported to have increased by 22% on average as a result of tillage from a total of 38 experiment years (Nicou and Charreau, 1985). When tillage is combined with fertilization and the use of crop residues, plowing improved soil productivity and crop yield with time, even in the driest years (Pieri, 1985).

Although not a problem at the ISC, some sandy soils in the Sahel under millet are sensitive to crusting and seriously impede infiltration (Hoogmoed and Stroosnijder, 1984). For such soils, tied ridges improve infiltration (Stroosnijder and Hoogmoed, 1984), and with the use of this technique increases of millet and sorghum yields of 340% have been achieved (Perrier, 1987).

This paper reports a series of field experiments carried out in a sandy soil typical of millet fields in Niger. The experiments were designed to evaluate (interaction) effects of seed size, depth and method of planting, millet variety, pre-sowing tillage, and soil fertilization on emergence, establishment, and yield of pearl millet.

MATERIALS AND METHODS

Experiment 1: Field emergence and establishment as affected by seed size, sowing depth, and variety

The effects of seed size and depth of planting on field emergence and establishment of two improved (cv. 'CIVT', and cv. '3/4 HK') and one local millet variety (cv. 'Sadoré local') were studied in the 1985 rainy season. The improved seeds were certified, the local variety seeds were taken from the previous year's bulk harvest.

Laboratory measurements

We used standard wire mesh sieves to obtain small (less than 1.95 mm), medium (1.95–2.12 mm) and large (more than 2.12 mm) seed fractions.

We determined the thousand grain weight and germination for each variety and seed size in four replications. Seeds were placed in petri dishes on moistened filter paper. Germination was considered successful when a radicle and plumule appeared. Germination, determined after 3 days, was expressed as a percentage of the total number of seeds.

Field measurements

The design was a randomized block full factorial experiment with five replications. Planting depths were 1, 3, 5 and 7 cm. Each sub-plot consisted of a single 5 m row. Row spacing was 0.75 m. Within-row hill spacing was 0.5 m. The seeds were sown in hills after 15 mm of rain on a flat, hand hoed field. The hill planting system was as follows: a hand held, thin walled hollow tube (5 cm diameter) was used to extract the moist soil to the required depth. Forty seeds were then emptied into the hole, and the soil core put back in its original position. No fertilizers were applied.

We evaluated crop emergence in terms of percentage of hills emerged at 5, 8 and 17 days after sowing (DAS). A hill was considered emerged when at least three seedlings were present. In addition, emergence was determined by counting all seedlings at 10 DAS. Establishment was evaluated in terms of average seedling dry matter per hill, and the number of secondary roots per seedling, both determined at 24 DAS from three to five hills per sub-plot.

There was 1 mm of rain at 3 DAS followed by 30.3 mm at 4 DAS, 34.2 mm at 5 DAS, and 6 mm at 11 DAS. The maximum soil temperature at 1 cm depth was 46.7 °C, measured at 3 DAS.

Experiment 2: Effect of sowing method and fertilization on establishment and yield

Two sowing methods, sowing in hills (comparable to the traditional method), and drilling seeds were compared at two fertility levels during the 1984 rainy season in a randomized block factorial experiment with four replications. 'Sadoré local' was sown using a tractor-mounted four-row unit planter. The planter was modified in-house in two ways. Each unit was fitted with a cone seed metering system. The system enables a uniform flow of a given amount of seed into the furrow over the length of the plot. In addition, the bottom end of each seed tube was fitted with a solenoid activated valve. In the hill-sowing mode the valves are closed, so that the metered flow of seeds accumulates at the bottom of the seed tube. The valves open momentarily after a set distance traveled, releasing seeds into the furrow, over a short (0.10–0.15 m) interval. This insured, independently of the sowing mode, a consistent seeding rate and depth (3–4 cm), as well as uniform packing. Where hills were sown their distance in the row was set to 1 m. Fertilizer rates were: (i) no fertilizer added; (ii) 17 kg ha^{-1} of P (as triple superphosphate) before sowing plus 40 kg ha^{-1} of N (as calcium ammonium nitrate) in a split application 2–3 and 4–6 weeks after sowing. Plots consisted of 12 rows 20 m in length and 0.75 m apart.

We measured crop stands at 3 and 13 DAS. Plant height was measured at 13 DAS. Two weeks after sowing the crop was thinned to three plants per hill and a corresponding three plants m^{-1} in drilled rows. The crop was allowed to mature, and grain yields were determined.

Experiment 3: Effect of primary tillage, fertilization, and variety on establishment and yield

During the 1984, 1985, and 1986 rainy seasons we evaluated the effect of pre-sowing tillage and fertilization on crop emergence, establishment and yield. The design was a randomized block factorial experiment with four replications. The following four tillage treatments were compared: (i) plowing to a depth of 0.15 m (using a Massey Ferguson Model 765 disk plow[1] fitted with three disks); (ii) ridging without prior tillage (using a John Deere 984 integral four-row bedder with staggered disks set to a ridge spacing of 0.75 m and ridge height of 0.15 m); (iii) 'sand fighting' (using an in-house 3-m-wide sand fighter); (iv) a no-till control. Plot size was 9 m × 20 m. Tillage was executed yearly, after the first rain event in May or June that exceeded 8 mm. Sand fighting was repeated during crop establishment using a 0.6-m-wide an-

[1]Trade names do not constitute endorsement of or discrimination against any product by the Institute.

imal drawn sand fighter between rows after any significant rain. Annual fertilizer rates and timing of application were identical to those of Experiment 2. Phosphorus was applied before tillage. In 1984, 'Sadoré local' was hill planted at a depth of 3–5 cm with 1 m between hills in rows spaced at 0.75 m, perpendicular to the prevailing (easterly) direction of erosive winds.

Improved millet varieties ('CIVT' and '3/4 HK') and residual fertility effect were added as treatments from the second year. Fertilizer sub-plots were split after the first year to assess the residual effect of fertilization. Pre-sowing tillage, and fertilizer treatments remained permanently assigned to plots. The crop was thinned to three plants per hill about 3–4 weeks after sowing. Weeding was done by hand twice per season. No crop protection measures other than bird scaring were taken.

We measured emergence and stand survival in terms of percentage of hills sown at various dates during the crop cycle. Daily total rainfall was also measured. To assess the stability of effects of tillage and fertilization over the years, we made a combined analysis of data over the years 1985 and 1986. We did not include the year 1984, because of the additional treatments executed in that year. We analyzed crop stands at harvest, grain yield per hill harvested, and total grain yield.

Experiment 4: Effect of primary tillage, fertilization, variety, and residue management on establishment and yield

This experiment, performed during the 1985 and 1986 rainy seasons, included the same factors as Experiment 3, but with larger plots. This was done because the possible beneficial effects of wind erosion control measures due to tillage could have been masked owing to border effects in the smaller plots used. The experiment was a split plot with three replications, with tillage assigned to main plots 30 m × 30 m in size. The first split was assigned to fertilization, the second to variety and the third to crop residue management. Presowing tillage, and fertilizer treatments were identical to those of Experiment 3. The local variety, 'Sadoré local', was compared with 'CIVT'. Crop residue management compared mulching of millet stalks with the removal of crop residues. All treatment combinations were permanently assigned to plots.

In the first (1985) rainy season, after sowing, millet residues were added at a rate of 4 t ha^{-1}. In 1986 we used the residue of the 1985 crop as mulch. As a result of the tillage treatment, these residues were incorporated in plowed plots, partially incorporated in the ridged plots, anchored in the sand-fought plots, or left on the surface in no-till plots. Weeding operations were identical to those for Experiment 3. No crop protection measures other than bird scaring were taken. We evaluated initial crop stand (measured at 16 DAS in 1985, and 18 DAS in 1986), crop stand at harvest, and grain and stover yields. We made a combined analysis of data over the 2 years of the experiment.

RESULTS AND DISCUSSION

Experiment 1: Establishment effects of seed size, sowing depth, and variety

Laboratory measurements

Germination is shown as a function of thousand grain weight in Fig. 1. Germination varied with variety, with '3/4 HK' having good germination for the three seed sizes. Germination of 'CIVT' and 'Sadoré local' was lower, and decreased with seed size, particularly for the local variety.

Field measurements

Depth of sowing was the only significant effect on the percentage of hills emerged, for all dates measured. Maximum hill emergence was observed at 8 DAS. At 17 DAS, stands had somewhat declined with significantly lower stands for the smallest seed size. No interaction effects occurred at any of the three dates (Table 1).

Seedling emergence at 10 DAS was significantly ($P<0.001$) affected by depth of sowing, seed size, and variety (Table 2). There was a small but significant ($P=0.022$) seed size by variety interaction, with emergence dropping off for the small seed fraction of 'Sadoré local' (data not shown), similar to the laboratory results.

Seedling shoot dry weight was significantly affected by sowing depth, variety ($P<0.01$), and seed size ($P<0.001$). A similar small significant seed size by variety interaction as observed with seedling emergence was present (data not shown). The number of secondary roots was independent of sowing depth, but seed size increased the number of secondary roots significantly ($P<0.001$). Variety also affected roots, with 'CIVT' having the most roots ($P<0.001$).

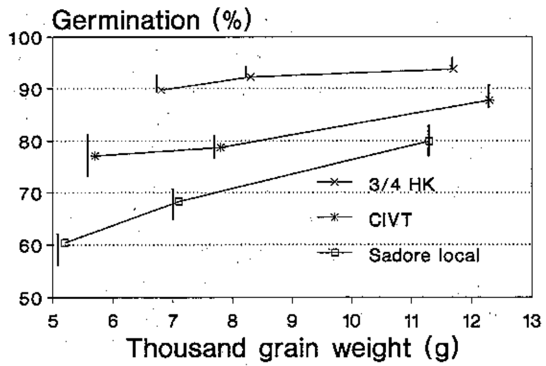


Fig. 1. Relationship between thousand grain weight and laboratory germination of three seed fractions for three millet varieties. Vertical bars indicate standard errors of germination. Standard errors of thousand grain weights are less than 0.46 g.

TABLE 1

Effect of sowing depth and seed size on emergence of hills in the 1985 rainy season

Treatment	Emergence (% of hills sown)		
	5 DAS	8 DAS	13 DAS
Depth of sowing (cm)			
1	85.1	86.2	84.2
3	91.6	92.4	90.4
5	93.1	94.0	90.7
7	91.3	90.7	86.7
SE	±1.7	±1.6	±1.7
Seed size			
Big	91.5	91.2	90.5
Medium	91.7	90.8	89.5
Small	87.7	90.5	84.0
SE	±1.4	±1.4	±1.5
CV(%)	12	12	13

The highest percentage of hills initially emerged and survived for the intermediate sowing depths. Intermediate depth of sowing produced on average 52% seedling emergence, thus significantly outperforming shallow and deep sowing. A similar apparent optimum sowing depth of 3 cm for two millet varieties in a sandy soil is reported by Hoogmoed (1981). Seedling emergence from both the shallowest and deepest sown seeds was inferior to those of the intermediate sowing depths, and had also the lowest shoot mass. We observed some removal of freshly sown seeds by ants and rodents, the latter continuing to dig up young seedlings. This could account for the inferior performance of the shallow sown seeds. Rainfall distribution resulted in good soil moisture availability and prevented the build-up of sustained high soil temperatures. The maximum soil temperature at a depth of 1 cm occurring at 3 DAS was 46.7°C, well below temperatures reported by Soman et al. (1987) of 51±3.2°C after 12 days of dry weather. It is suggested that, for the deepest planted seeds which emerged only half a day later, more of the nutrient reserve contained in the seeds was depleted, leaving the seedling in a weaker condition at emergence.

Experiment 2: Effect of sowing method and fertilization on establishment and yield

Emergence was higher in drilled plots than in hill planted plots, but early survival and development of seedlings were inferior. Two storms occurring between 3 and 13 DAS with high windspeeds produced ideal conditions for

TABLE 2

Effect of depth of sowing, seed size, and variety on seedling emergence at 10 DAS (percentage of seeds sown), shoot dry weight at 24 DAS, and number of secondary roots per seedling at 24 DAS, 1985 rainy season

Treatment	Emergence (% seeds sown)	Shoot dry weight (g per hill)	Secondary roots (no. per seedling)
Depth of sowing (cm)			
1	43.0	2.85	3.30
3	51.4	3.77	3.17
5	52.7	3.92	3.21
7	45.6	2.92	3.05
SE	±0.4	±0.24	±0.07
Seed size			
Big	54.0	5.11	3.51
Medium	50.6	3.15	3.11
Small	39.9	1.82	2.91
SE	±1.2	±0.21	±0.06
Variety			
'3/4 HK'	56.4	3.35	3.00
'CIVT'	48.0	3.85	3.36
'Sadoré local'	40.0	2.89	3.18
SE	±1.1	±0.21	±0.06
CV(%)	19	49	15

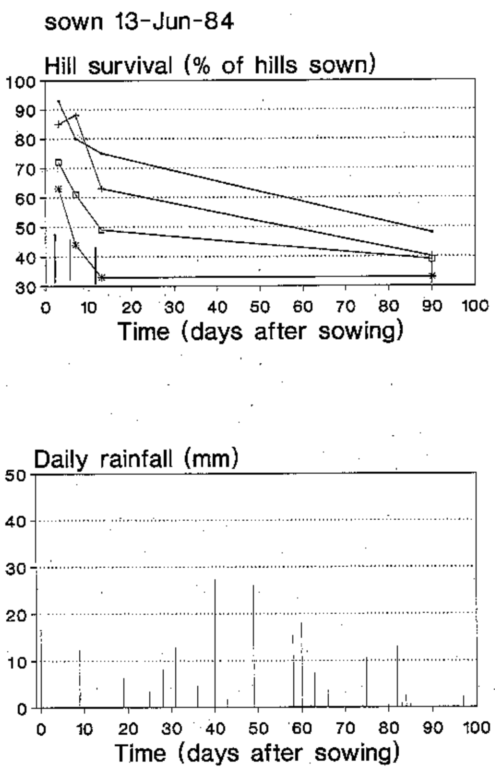
wind erosion. Average millet seedling stands at 13 DAS in drilled plots dropped from 198 000 to 134 000 seedlings ha^{-1}. The average total number of seedlings in hill planted plots was 107 000 ha^{-1}, while the number of hills dropped by 9% to an average of 10 400 hills ha^{-1}. However, maximum seedling height in hills was 16.9 cm, significantly greater than the height of 10.2 cm observed in drilled rows (SE±0.86). Possibly because of temperature effects and sand blast protection of the innermost seedlings, growth conditions for surviving seedlings in hills had been more favorable. There were no fertility, nor fertility by sowing methods effects during this stage.

From sowing until harvest only 190 mm of rainfall was received. Yields and yield responses to treatment factors were therefore low. There were no significant sowing method by fertilization effects. However, the grain yield of drilled seeds (0.27 t ha^{-1}) was significantly lower than that of hill sown seeds (0.34 t ha^{-1}) (SE±0.031). The use of fertilizer increased yields from 0.25 to 0.36 t ha^{-1} (SE±0.031).

Experiment 3: Effect of primary tillage, fertilization, and variety on establishment and yield

Three consecutive seasons were quite different in terms of storm frequency, characteristics, and total rainfall received. The effects of pre-sowing tillage on crop stands are presented in Fig. 2. In 1984, the first rain-bearing storm occurred at 9 DAS and a second at 19 DAS. Both storms were characterized by high winds, in both cases blowing over an already dry soil surface. The resulting sand blasting reduced crop stands markedly. In 1985, during the 20 day period following sowing, there were five storms, all much less violent in terms of wind. As a result of the wetter topsoil and reduced erosive force of the wind during the storms, conditions for crop establishment were most favorable of the 3 years studied. In 1986, no substantial rains were received until 17 DAS. However, a series of highly erosive wind storms occurred at 10, 11, and 16 DAS. Because the soil surface was dry by then, wind-blown sand caused a considerable decline in stands. Common to all years is the consistent and significant effect that pre-sowing tillage had on early stands. Plowing and ridging produced the best stands. Also common was the fact that neither fertilizer nor its interaction with tillage significantly affected early crop stands.

The low rainfall received in 1984 masked the earlier stand advantages gained from tillage. Only the addition of fertilizer increased crop grain yield from 0.28 to 0.39 t ha^{-1} (SE$\pm$0.031). Average results for crop stand at harvest, grain yield per hill and grain yield ha^{-1} for 1985 and 1986 are presented in



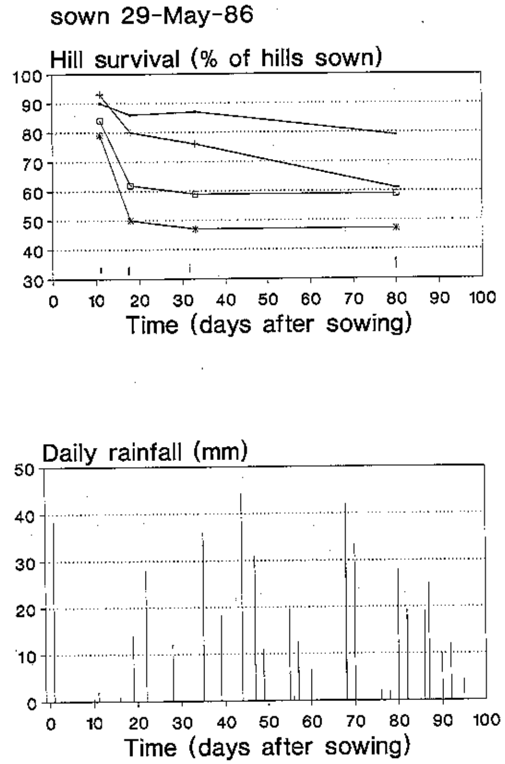


Fig. 2. The effect of pre-sowing tillage on average pearl millet stands (percentage of 13 300 hills ha^{-1} sown) over time, for the rainy seasons of 1984, 1985, and 1986. □, no-till; *, sand fighting, +, ridging; ■, plowing. Vertical bars indicate standard errors.

Table 3. The year by management tillage and fertilization interactions were not significant, indicating the consistency of the effects of these treatments. The tillage by fertilization interaction was significant ($P<0.05$) for crop stands and grain yield ha^{-1}. On non-fertilized plots, crop stands were best assured by plowing, resulting in the highest grain yield ha^{-1}. Fertilization was the single most important factor increasing grain yield per hill. Allied with superior hill survival following plowing or ridging, yields almost doubled when compared with sand fighting and no-till.

Varietal differences in grain yield were significant, average grain yields were 0.22 t ha^{-1} for '3/4 HK', 0.40 t ha^{-1} for 'CIVT', and 0.41 t ha^{-1} for the local variety. The residual effect of fertilization was limited to crop stand survival, with average stands increasing from 56 to 63.4% (SE$\pm$1.75).

The positive effect of plowing and ridging on early stands probably arises from reduced soil bulk density which is conducive to root proliferation. The addition of fertilizer contributed to more vigorous and sustained growth in the hills that survived. The advantages of pre-sowing tillage over no-till might

TABLE 3

Tillage and fertilization (interaction) effect on pearl millet stand at harvest (percentage of hills sown), grain yield per hill, and total grain yield, average of three millet varieties, average for the rainy seasons of 1985 and 1986

Treatment	Hill survival (% hills sown)			Grain yield (g per hill)			Grain yield (kg ha^{-1})		
	F0	F1	Mean	F0	F1	Mean	F0	F1	Mean
Plowing	67.9	87.4	77.6	25.3	57.4	41.4	254	681	467
Ridging	43.5	80.4	61.9	24.4	57.6	41.0	180	649	414
Sand fighting	30.6	63.1	46.8	22.0	37.2	29.6	89	352	220
Zero-till	41.8	63.2	52.5	18.6	42.0	30.3	139	402	271
SE	±3.2			±5.1			±40		
Mean	45.9	73.5		22.6	48.6		165	521	
SE	±1.4		±2.5	±2.3		±3.9	±15		±33
CV (%)	33			56			60		

F0, no fertilizers applied; F1, fertilizers added.

be offset by a delay in sowing. However, Hoogmoed and Klaij (1990b) calculated for the Niamey region that there was a 40% probability of receiving a first storm sufficient for 2.3 days of tillage, but unsuitable for planting. For the years in which this did not occur, possible yield advantages from no-till associated with early sowing would likely be partly nullified, as stands and stand survival would probably be in this case equally affected by environmental conditions, while foregoing the more vigorous growth per hill resulting from tillage.

Experiment 4: Effect of primary tillage, fertilization, variety, and residue management establishment and yield

The considerably larger plots used for tillage in this experiment, compared with Experiment 3, did not alter its effects on crop stands and yield (Table 4). Results were quite similar to those found in Experiment 3. The year by tillage or fertilization effect was insignificant, indicating the consistent performance of tillage and fertilization treatments. However, there was no statistically significant tillage by fertilization interaction effect. Crop stands, determined after sowing and at harvest, confirm the significant positive effect that pre-sowing plowing or ridging had on initial stands and their survival. In contrast to Experiment 3, fertilization also improved initial stands.

Crop yields were significantly affected by fertilizer application and pre-sowing tillage. Fertilization increased crop grain and stover yields almost threefold. Plowing or ridging improved yields threefold over the sand fight and no-till treatments. As in Experiment 3, stands accounted for only part of the improved crop production brought about by tillage and fertilization.

TABLE 4

Effect of pre-sowing tillage, millet variety, fertilization, and crop residue on plant population (percentage of 13 300 hills ha^{-1} sown) and crop yield components. Average for the rainy seasons of 1985 and 1986

Treatment	Crop stand (% of hills sown)		Crop yield (t ha^{-1})	
	Initial	Harvest	Grain	Stover
Cultivation				
Plowing	72.2	72.2	0.591	1.94
Ridging	79.7	69.9	0.518	1.71
Sand fighting	51.1	43.6	0.200	0.89
Zero-till	51.1	39.8	0.221	0.78
SE	±5.0	±4.2	±0.079	±0.19
CV (%)	19	18	51	34
Variety				
'CIVT'	69.9	59.4	0.354	1.01
'Sadoré local'	57.1	54.9	0.412	1.66
SE	±1.9	±1.2	±0.014	±0.04
CV (%)	21	15	25	20
Fertilization				
No	58.6	46.6	0.195	0.69
Yes	68.4	66.2	0.570	1.97
SE	±2.3	±2.0	±0.033	±0.16
CV (%)	18	17	42	32
Crop residue				
Removed	61.4	54.2	0.366	1.25
Left	65.7	58.6	0.399	1.41
SE	±1.7	±1.2	±0.018	±0.05
CV (%)	26	20	46	39

The use of crop residues showed a significant treatment by year interaction, possibly resulting from a cumulative amelioration of soil conditions over time. Crop stover yields in 1985 were 1.04 t ha^{-1} on plots without crop residue, and 0.98 t ha^{-1} on plots with crop residues left. In 1986, these yields were 1.46 t ha^{-1} and 1.85 t ha^{-1} respectively. Grain yields also responded significantly (data not shown).

The local variety had significantly higher grain, and stover yields than 'CIVT'. The much larger plots used did not improve the performance of sand fighting over no-till; the clods produced by sand fighting were not sufficiently stable to reduce the wind erosion hazard in this case.

CONCLUSIONS

Seed size, sowing method and depth improved emergence and establishment of pearl millet substantially. For the sandy soil studied, an optimum sowing depth of 3–5 cm was found. Hill sowing was far superior to drilling in terms of seedling survival and crop yield. With the indigenous hill sowing method, a fair portion of the seeds sown will fall within the optimum depth band. Selecting the biggest seeds, and maintaining the proper sowing depth requires skill only on the part of the farmer. Whether or not these crop establishment advantages ultimately lead to yield increases depends on other factors such as soil fertility management and pre-sowing tillage.

A total of six experiment years on replicated factorial experiments show the consistent advantage that modest doses of P, and N fertilizers together with pre-sowing tillage have on pearl millet production. Crop establishment improves, stands at harvest are better assured and yield per hill is much higher. Application of chemical fertilizer consistently increased millet grain and stover yields about threefold in close to normal years, while a 50% increase in grain yield was obtained in the driest year on record. These substantial gains are realized by a scale neutral input. Grain and stover yields on non-fertilized plots were increased two- to threefold by pre-sowing plowing or ridging, and sixfold when fertilizer application was combined with pre-sowing tillage.

The tillage methods used, particularly ridging, can well be carried out by animal traction. In the Niamey climatic region, pre-sowing tillage advantages not offset by delayed sowing can be expected in 4 out of 10 years.

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