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Soil & Tillage Research 39 (1996) 31-43

Soil & Tillage Research

Weeding method and pre-sowing tillage effects on weed growth and pearl millet yield in a sandy soil of the West African Sahelian zone

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Accepted 23 May 1996

Abstract

Weed control for the West African Sahel rainfed crops is done mainly manually, resulting in high labor requirements. Because of the seasonality of rainfed farming, weed control is often late and incomplete, resulting in considerable losses in crop yield. We examined the case of weed control in continuously cultivated pearl millet (*Pennisetum glaucum* (l.) R. Br.) on a sandy soil. During 3 years we evaluated the effects of pre-sowing ridging and combinations of hand and mechanical weeding powered by donkeys on: seasonal weed growth (separating within-row and between-row weeds), pearl millet yield, and labor requirements for weeding. Four weeding methods resulted in levels of weed control decreasing in the order: full field hand weeding (W_f); between-row weeding by animal traction plus additional within-row hand weeding (W_{a+h}); between-row weeding by animal traction (W_a); and no weeding (W_0). Weeding method was the single most important factor that affected weed growth and, hence crop yields. Depending on the year, average weed dry matter at harvest ranged from 140 to 270 kg ha^{-1} for method W_f to 3000 to 3520 kg ha^{-1} for method W_0. Correspondingly, the highest millet yields ranging from 279 to 1012 kg ha^{-1} were obtained with W_f with a total weeding labor requirement of 70.1 h ha^{-1}. The W_{a+h} method required 51.8 h ha^{-1} and resulted in yields, depending on the year, that were 78 to 100% of the W_f method. The W_a method resulted in unchecked within-row weed growth that exceeded those in weedy check plots, and reduced crop yield to 28 to 34% of W_f. Finally, unchecked weeds reduced yield to 2 to 10% of W_f.

Pre-sowing tillage reduced seasonal weed growth, increased crop yields, and was particularly

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PII S0167-1987(96)01049-5

effective in reducing the amount of crop weeds for the W_a weed control method. The continuous growing of millet did not change the amount of seasonal weed dry matter during the experiment.

Keywords: Tillage; Mechanical and manual weed control; Pearl millet yield losses; Within-row and between-row weed growth; Alfisol; Semi-arid tropics

1. Introduction

The seasonality of rainfed field crop cultivation imposes a serious bottleneck in terms of time and amount of weeding, particularly where weeding is commonly dependent on manual labor (Norman et al., 1981). As many as 256 h ha^{-1} in Senegal and 129 h ha^{-1} in Mali are reported to be required for weeding for the cultivation of pearl millet and sorghum (*Sorghum bicolor* (L.) Moench) (Norman et al., 1981). Somewhat lower work rates are estimated for the millet-based subsistence cropping systems typical of the sandy soils of Niger. In a replicated large plot experiment, hand weeding required 148 h ha^{-1} in 1986 and 95 h ha^{-1} in 1987 (International Crops Research Institute for the Semi-Arid Tropics, ICRISAT, 1988). Late and incomplete weeding is common in the Sahel and results in potential crop yield losses.

Crop yield losses caused by uncontrolled weeds are as high as 70% in India for millet and sorghum (ICRISAT, 1976), and ranged from 10 to 90% in experiments on mechanical weed control for millet and sorghum (Klaij, 1983). In the savannah area of Northern Nigeria grain losses were 71% for millet (Choudhary and Lagoke, 1981). Millet grain losses associated with farmers weeding practices ranged from 27 to 36% for early millet in the Gambia (Carson, 1987). These losses were attributed to poor land preparation and lack of within-row weeding. Indeed, primary tillage plays an important role in year round weed management (Kuipers, 1975).

In the West African Sahelian zone fallow periods have been shortened and millet is increasingly grown continually, which has implications both for crop yield and weed management. Considerable research has been invested in developing more intensive cultivation methods for millet using low levels of external inputs. Pre-sowing ridging using animal traction, application of modest doses of phosphorus fertilizer, and use of increased plant densities have increased millet yields substantially (Klaij et al., 1994). Between-row weeding with donkey drawn weeders reduced farmers' weeding effort by 50% (ICRISAT, 1991). However, little research has been reported in the region on weeding time requirements, the effects of pre-sowing tillage and weeding on weed growth, and the potential losses of a millet crop. Therefore, we conducted a 3-year study to evaluate the effectiveness of pre-sowing tillage, combinations of hand weeding and animal-powered between-row weeding, and millet cultivar on seasonal weed growth and crop yield components.

2. Materials and methods

2.1. Experimental site

The study was conducted from 1987 to 1989, at the ICRISAT Sahelian Center (13°48′N; 5°15′E, altitude 272 m), 45 km south of Niamey, Niger. Soil and climate parameters have been described in detail by Hoogmoed and Klaij (1990). The soil is sandy with total sand (particle size 0.02 to 2.0 mm) decreasing from 920 g kg^{-1} at the surface to 890 g kg^{-1} at 1.5 m-depth, while clay (particle size < 2 μm) content increased from 40 g kg^{-1} to 80 g kg^{-1}. When wet, the topsoil is very friable, non-sticky, and non-plastic, attributes that greatly facilitate tillage and weeding. The soil is a sandy Psammentic Paleustalf: sandy, silicious isohyperthermic according to the USDA classification system (West et al., 1984). It is classified an Arenosol on the FAO/UNESCO soils map of 1977 (FAO/UNESCO, 1977). This soil is the major soil unit in the 60 to 100 days length of growing season band comprising the Southern Sahelian zone (ICRISAT, 1992). At the start of the experiment the soil had not been cultivated for 5 years. Soil organic matter content of the top 0.2-m layer was 4.2 g kg^{-1} soil (SE = 0.18) and P-$Bray_1$ was 6.2 μg g^{-1} soil (SE = 1.90). Mean annual rainfall in Niamey is 560 mm (1961–1990 rainfall data) with most of the rain received between June and September.

2.2. Experimental treatments

We evaluated the factors tillage, weeding and pearl millet cultivar. Annual pre-sowing ridging was compared with the traditional system that involves no primary tillage, further referred to as no-till. Ridges were made 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 0.20 m. Ridging was executed yearly, after the first rain in May or June that exceeded 8 mm. The weeding methods compared were aimed at increasing level of control: between-row cultivation only (W_a), between-row cultivation supplemented with in-row hand weeding (W_{a+h}), and full field hand weeding (W_f). A fourth treatment in which weeds were allowed to grow was included (W_0). Weeding was done twice each crop cycle. The between-row weeding for method W_a was done in a single pass using a donkey pulling an expandable weeder weighing 11 kg and fitted with three duckfeet set at 0.5-m width. Hand weeding in methods W_{a+h} and W_f was done using a local long handled push hoe typical for the sandy soils in Niger (Raynaut, 1984). A local pearl millet cultivar, Sadore local (110 days) was compared with an improved early maturing cultivar, CIVT (90 days).

Treatments were replicated six times in $4 \times 2 \times 2$ factorial experiment with the weeding method by tillage by cultivar interaction confounded with blocks of eight plots each. Treatments were permanently assigned to plots. The plot size was 3×20 m.

A blanket application of 13.1 kg ha^{-1} of P (single superphosphate containing boron in 1987, and single superphosphate in 1988 and 1989) was broadcast applied each season before sowing or tillage. In all plots nitrogen (calcium ammonium nitrate) was side dressed at a rate of 40 kg ha^{-1} in a split application, 2 to 3 and 4 to 6 weeks after sowing. Pearl millet was sown at a depth of 3 to 4 cm in hills spaced 0.66 m using a tractor mounted four row unit planter. In hill-drop planting a cluster of seeds is released at set intervals. Row spacing was 0.75 m. In ridged plots millet was sown on top of the ridge. Two to 3 weeks after sowing stands were thinned to obtain 10000 hills ha^{-1} with three seedlings per hill. Crop residues were removed each year. Dates of field operations

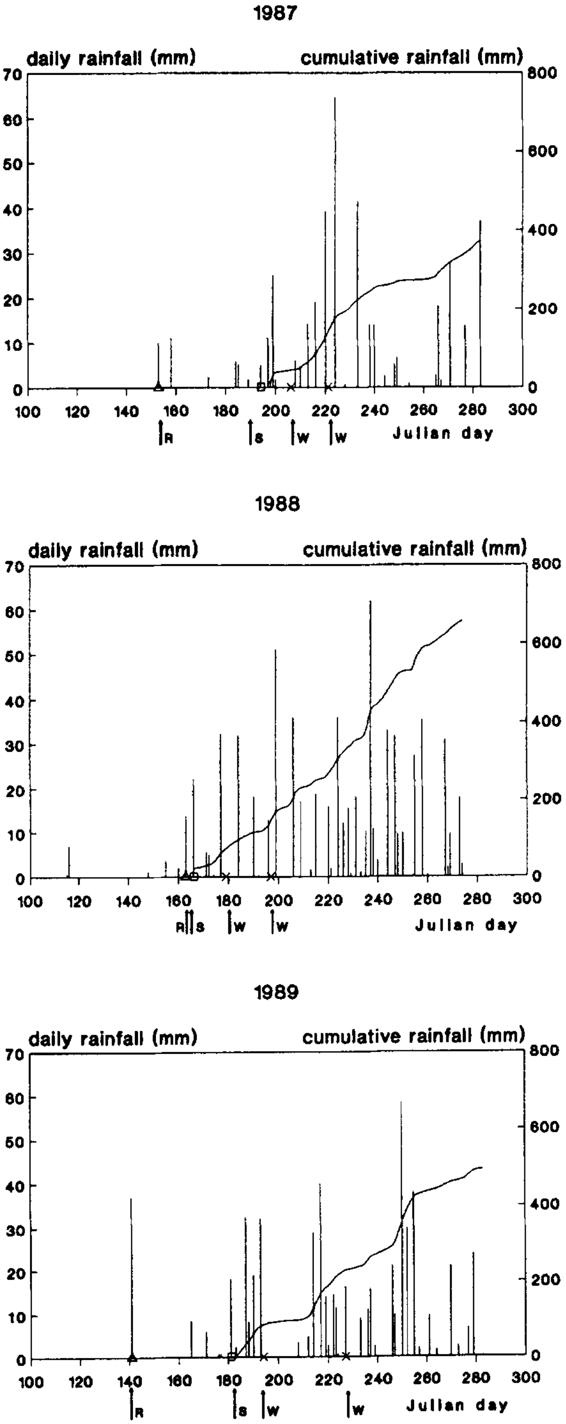

Fig. 1. Daily rainfall and cumulative rainfall for the 1987 to 1989 cropping seasons (R, dates of pre-sowing tillage (ridging); S, dates of sowing; W, dates of weeding).

depended on rainfall received (Fig. 1). Total rainfall received by the crop during the first 92 days after sowing was 361 mm in 1987, 581 mm in 1988, and 510 mm in 1989.

2.3. Weed and crop sampling techniques

In order to avoid border effects between weeds, and weeds and pearl millet, we divided each plot into two study areas, one half for weed sampling, the other for crop measurements.

Every year in each plot, weeds were sampled at four times during the crop cycle. Between-row and within-row weeds were separately cut at the soil surface, oven dried, and weighed. Experience with the donkey-powered weeder (W_a) showed that a 0.25-m wide strip centered in the crop row is left untouched. Therefore, weeds growing in this strip were considered within-row weeds and, having a 0.75-m row distance, within-row weeds would grow in 1/3, and between-row weeds in 2/3 of the field. To represent this proportion we demarcated each sampling area using a 1.50 × 1.33-m rectangular frame with the long side placed perpendicular to the row direction and centered over two rows. This way 2/3 m^2 of within-row weeds, and 4/3 m^2 of between-row weeds were sampled. Weed dry matter was calculated on an area basis.

We determined millet seedling vigor from shoot dry weight. Millet stands after thinning and at harvest, and millet grain and stover yields were determined from 15 m^2 of the two center crop rows.

Daily and cumulative rainfall following sowing during the crop cycles of 1987, 1988, and 1989 are presented in Fig. 1.

Labor requirements for the W_f and W_a weeding method were taken from a replicated large plot on-station field experiment in which millet was grown on a similar soil following the same agronomic practices.

Table 1
Abundantly present weeds in the experiment

Species	Family
Alysicarpus ovalifolius (Schume. and Thonn.) J.Leonard	Fabaceae
Aristida sieberiana Trin.	Poaceae
Borreria radiata D.C.	Rubiaceae
Chamaecrista mimosoides (L.) Greene	Caesalpiniaceae
Fimbristylis sp.	Cyperaceae
Indigofera pilosa Poir.	Fabaceae
Indigofera Strobilifera (Hochst) Hochst ex Bak.	Fabaceae
Lpomoea vagans Bak.	Convolvulaceae
Limeum viscosum (Gay.) Fenz.	Molluginaceae
Merremia pinnata (Hochst ex Choisy) Hallier f.	Convolvulaceae
Mitracarpus scaber Zucc.	Rubiaceae
Polycarpaealinearifolia (D.C.) D.C.	Caryophyllaceae
Sida cordifolia L.	Malvaceae
Spermacoce stachydea D.C.	Rubiaceae
Tephrosia linearis (Willd.) Pers.	Fabaceae
Tephrosia purpurea (L.) Pers.	Fabaceae
Waltheria indica L.	Sterculiaceae

2.4. Predominant weed species

The objective of the reported experiment does not include a detailed investigation into the effects of weed management on numbers, weight or shift of weed species. However, the predominant weed species were determined (G. Schmelzer, personal communication, 1989) (Table 1), and we approximately evaluated their seasonal occurrence in terms of area covered.

2.5. Statistical analysis

Data were analyzed by individual years and combined over years by analysis of variance using GENSTAT 5 release 3.

3. Results and discussion

3.1. Weed growth

Because of the significant effects of: year ($P \leq 0.001$), year by weeding method ($P \leq 0.001$), and year by pre-sowing tillage interactions ($P \leq 0.05$) for most sampling times, seasonal weed dry matter data are presented for individual years in Tables 2–4.

Table 2
Weeding, tillage, and cultivar effect on within-row and between-row weed dry matter (kg ha^{-1}) during the crop cycle of 1987. Weeding dates 12 and 27 days after sowing

Treatment	Sampling time (days after sowing)							
	Between-row				Within-row			
	19	31	72	93	19	31	72	93
Weeding method [a]								
W_0	118	868	2635	2957	121	929	3332	3815
W_a	20	65	797	1419	107	898	5241	5065
W_{a+h}	11	13	326	551	48	27	548	1011
W_f	5	8	76	206	57	19	191	395
SE [b]	7.7	33.6	91.9	126.0	7.0	57.5	199.2	212.6
Tillage								
No-till	47	270	1037	1306	78	453	2225	2342
Ridging	30	206	880	1260	88	483	2431	2802
Cultivar								
Sadore l.	37	214	957	1129	84	526	2503	2619
CIVT	40	263	960	1437	82	413	2153	2525
SE [c]	5.5	23.7	65.0	89.1	5.0	40.6	140.9	150.3

[a] W_0, no weeding; W_a, between-row weeding by animal traction; W_{a+h}, between-row weeding by animal traction plus additional within-row hand weeding; W_f, full field hand weeding.
[b] SE, standard error of means for weeding method.
[c] SE, standard error of means for tillage or cultivar.

Table 3
Weeding, tillage, and cultivar effect on within-row and between-row weed dry matter (kg ha^{-1}) during the crop cycle of 1988. Weeding dates 13 and 31 days after sowing

Treatment	Sampling time (days after sowing)							
	Between-row				Within-row			
	29	48	70	94	29	48	70	94
Weeding method [a]								
W_0	1282	2834	3082	2918	1143	2948	3715	3169
W_a	429	957	1680	1571	1433	3425	4338	4512
W_{a+h}	158	132	156	377	258	138	294	505
W_f	47	15	92	146	109	34	93	129
SE [b]	40.9	94.3	121.5	124.7	75.4	139.4	159.4	220.6
Tillage								
No-till	624	1100	1352	1316	947	1888	2513	2504
Ridging	333	869	1152	1190	525	1385	1707	1653
Cultivar								
Sadore l.	484	966	1266	1266	740	1713	2018	1902
CIVT	474	1033	1238	1240	732	1560	2203	2255
SE [c]	28.9	66.7	85.9	88.2	53.2	98.6	112.7	156.0

[a] W_0, no weeding; W_a, between-row weeding by animal traction; W_{a+h}, between-row weeding by animal traction plus additional within-row hand weeding; W_f, full field hand weeding.
[b] SE, standard error of means for weeding method.
[c] SE, standard error of means for tillage or cultivar.

3.1.1. Weeding method effects

Weeding method was the single most important factor significantly affecting dry matter of weeds between-row and within-row in all years at all sampling times. Compared with the weedy check, weed dry matter decreased as the amount of weed control increased from W_a to W_{a+h}, to W_f. The W_a method, potentially only controlling between-row weeds, was significantly less effective in doing so than the other methods. Furthermore, compared with the weedy check, within-row weed dry matter of the W_a method was significantly greater in 1987 and 1988 on the last two sampling times. We observed that the removal of competing between-row weeds had benefited the remaining within-row weeds whose canopies eventually touched between the millet rows. Additional hand weeding within the row as included in the W_{a+h} method decreased weed dry matter considerably, particularly at the first two sampling times, when weed crop competition effects are critical. The W_f method did not significantly decrease weed dry matters over the W_{a+h} method.

An important factor contributing to successful weed control relates to the difference in quality between hand and mechanical weeding. Betker (1991) found at the ICRISAT Sahelian Center, that one hand weeding killed 93%, while a single pass with the donkey-drawn weeder killed only 30% of the weeds in a millet crop having a dry matter weed infestation of 75 kg ha^{-1}. These data compare well with the between-row weediness levels of the W_a and W_{a+h} weeding treatments. Obviously, conscientious hand weeding delivers the highest quality in weed control (Terry, 1981).

Table 4
Weeding, tillage, and cultivar effect on within-row and between-row weed dry matter (kg ha^{-1}) during the crop cycle of 1989. Weeding dates 13 and 46 days after sowing

Treatment	Sampling time (days after sowing)							
	Between-row				Within-row			
	29	47	69	93	29	47	69	93
Weeding method [a]								
W_0	1174	2379	3152	3674	1138	2185	2654	3225
W_a	605	1256	1046	1537	554	1799	2428	3257
W_{a+h}	120	531	636	1106	76	270	154	1034
W_f	17	134	62	248	47	158	82	460
SE [b]	52.7	105.6	133.7	179.1	69.6	163.2	150.6	248.3
Tillage								
No-till	728	1255	1290	1612	682	1350	1558	2294
Ridging	230	894	1158	1670	225	856	1101	1694
Cultivar								
Sadore l.	521	1020	1279	1651	425	1063	1352	2010
CIVT	438	1133	1169	1631	482	1143	1307	1978
SE [c]	37.2	74.7	94.5	126.6	49.2	115.4	106.5	175.6

[a] W_0, no weeding; W_a, between-row weeding by animal traction; W_{a+h}, between-row weeding by animal traction plus additional within-row hand weeding; W_f, full field hand weeding.
[b] SE, standard error of means for weeding method.
[c] SE, standard error of means for tillage or cultivar.

3.1.2. Tillage effects

Compared with no-till, pre-sowing ridging significantly reduced the amount of within-row weeds throughout the seasons of 1988 and 1989 by 33 to 74%. In 1987, there was no difference in the amount of within-row weeds, except at harvest when ridging resulted in 20% more weeds. In all years, an important reduction of 32 to 79% in between-row weed dry matter was noted during the first two sampling times (not significant at 31 days after sowing (DAS) in 1987). This is a crucial timely reduction since the critical competition period is during the early life of the crop. For instance, sorghum and millet in India produced the highest yield when the crops were kept weed free for the first 6–7 weeks (ICRISAT, 1976).

We found a significant tillage by weeding method interaction effect on average weed dry matter both in 1988 and 1989 at 29 DAS, after one weeding. In this early stage of crop growth ridging enhanced weed control by the W_a weeding method, which had a significantly reduced (by 20 to 30%) weed dry matter compared with plots without primary tillage (Table 5).

The effectiveness of pre-sowing ridging in reducing weeds seems to be related to the occurrence of storms before and after tillage, and the delay in sowing after tillage. For instance, in 1987 there was no rain before the one storm that allowed tillage, but four storms of > 5 mm occurred after tillage in the period of 42 days until sowing (Fig. 1). Consequently, weeds had emerged before sowing rendering weed competition almost as intense as under no-till conditions. In contrast, in 1988 two small storms provoked

Table 5
Interaction of pre-sowing tillage and weeding on average weed dry weight (kg ha^{-1}) at 29 days after sowing

Treatment	Season					
	1987		1988		1989	
	No-till	Ridge	No-till	Ridge	No-till	Ridge
Weeding method [a]						
W_0	968	768	1510	1053	1737	538
W_a	89	41	658	199	858	249
W_{a+h}	16	9	258	58	97	55
W_f	8	8	71	23	35	58
SE [b]	47.5		57.9		98.5	

[a] W_0, no weeding; W_a, between-row weeding by animal traction; W_{a+h}, between-row weeding by animal traction plus additional within-row hand weeding; W_f, full field hand weeding.
[b] SE, standard error of means of treatment interaction.

germination of weeds, which were subsequently covered by ridging. As ridging was followed immediately by sowing, there was an early advantage to the crop. In 1989, the pattern appears to be similar to that of 1987, except that in the 2-week dry period following tillage, emerged weeds died.

Because millet yields would be affected by both within-row and between-row weeds, we also analyzed treatment effects for the total weed dry weight (data not shown). We found similar tillage by weeding method interactions as for the within-row and between-row weeds analysis. There was no evidence that growing millet for 3 consecutive years, increased the amount of weeds, with the weedy check producing on average 3260 kg ha^{-1} of weed dry matter each year. However, the weed composition, determined in 1988 and 1989, changed depending on weeding method and tillage. In 1988 we found leguminous weeds occupying an increasing soil surface area during the season in non-weeded plots. Increasing the amount of weeding created a shift to broadleaved weeds and an associated reduction of the area covered by grassy weeds. Trends were similar during the 1989 season, but the leguminous weeds disappeared. Ridging had a similar effect on weed composition as weeding with untilled plots having about twice as many grasses as did ridged plots.

3.1.3. Cultivar effect

No significant differences were found between the cultivars used in their capability to smother weeds, except for between-row weeds at harvest in 1987, when we found 1129 kg ha^{-1} of weed dry matter for the local compared with 1437 kg ha^{-1} for CIVT. This could be expected as early in the season growth differences between the two cultivars are small, with the local variety eventually producing more biomass than the shorter duration CIVT.

3.2. Millet yield

Total rainfall received during the cultivation of the crop, and its distribution resulted in water not being an important limiting factor on crop yield. For instance during the

Table 6
Effect of pre-sowing ridging on pearl millet establishment (shoot dry weight in g per hill)

Treatment	Season and days after sowing (DAS)		
	1987 14 DAS	1988 10 DAS	1989 30 DAS
Tillage			
No-till	1.9	1.1	4.9
Ridging	2.6	4.6	9.3
SE [a]	0.10	0.08	0.50

[a] SE, standard error of means.

1987 season, in which the crop received 361 mm, yields were about the same as in the 1988 season during which 582 mm was received. However, the 14-day dry period early in the season of 1989 (Fig. 1), and a severe infestation by a head worm Raghuva (*Heiliocheilus* (*Raghuva*) *albipunctella*) might have contributed to the substantially reduced yields for that year.

In all years millet seedling vigor was significantly greater in ridged plots than in plots without primary tillage; however, in 1987 the effect was minimal (Table 6). Millet seedling vigor is consistent with its early advantage over weeds in 1988 and 1989, depending on the weather which dictated the timing of ridging and sowing, as discussed earlier. During the experiment there were no significant treatment effects on crop stands up to harvest. Hence, the treatments did not affect crop yields by their effect on stands. The exception occurred in 1989, when at harvest stands in the W_0 plots had been reduced to about 80% of the average stands (data not shown).

In all years, pre-sowing ridging significantly increased both grain yield by 58 to 71%, and stover yield by 56 to 82% over the no-till treatment, with the exception of grain yield in 1987 (Table 7). There was an important interaction between the effects of tillage and weeding method on millet yields. The trend was similar for both grain and stover yields (data not shown) and indicated that pre-sowing ridging becomes increasingly important in controlling weeds, and hence in influencing crop yields, as the amount of weed control in the crop becomes lower (Table 8).

During the experiment the sum of weed dry matter and crop dry matter was virtually constant for all weeding methods (Tables 2–4 and 7). Thus treatment effects reflected a shift in the competition between the crop and the weeds. The amount of weed control was the most important factor in controlling seasonal weed levels, and it consistently and significantly influenced millet yields. The highest average millet grain yields were obtained with the W_f method. Almost as effective was the W_{a+h} method, producing millet grain yields of 78 to 100% of the W_f method, depending on the year. Lastly, the W_a method resulted in considerably lower crop yields which were between 28 to 34% of those with the W_f method. Such a yield loss cannot be compensated for by the modest reduction in labor rates associated with this weeding method.

3.3. Weeding labor requirements

The W_a weeding method required 21.2 h ha^{-1} while the W_f weeding method required the highest labor rate of 70.1 h ha^{-1}. Method W_{a+h}, combining mechanized weeding

Table 7
Effect of weeding, tillage, and variety on millet grain and stover yield (kg ha^{-1})

Treatment [a]	Grain yield			Stover yield		
	1987	1988	1989	1987	1988	1989
Weeding method [b]						
W_0	100	50	6	307	354	23
W_a	326	287	87	844	1055	330
W_{a+h}	835	1012	218	1777	3167	719
W_f	952	1012	279	2174	3192	1055
SE [c]	51.6	58.7	23.9	102.6	171.5	97.2
Tillage						
No-till	663	640	143	1445	2114	503
Ridging	745	901	246	1752	2829	900
SE [d]	42.1	47.9	19.5	83.7	140.1	79.3
Cultivar						
Sadore local	819	863	230	1942	2900	885
CIVT	589	678	160	1256	2043	517
SE [e]	42.1	47.9	19.5	83.7	140.1	79.3

[a] W_0 values were excluded from the analyses of variance for the calculation of standard errors of means. Means of tillage and cultivar levels are calculated excluding W_0 levels.
[b] W_0, no weeding; W_a, between-row weeding by animal traction; W_{a+h}, between-row weeding by animal traction plus additional within-row hand weeding; W_f, full field hand weeding.
[c] SE, standard error of means for weeding method.
[d] SE, standard error of means for tillage.
[e] SE, standard error of means for cultivar.

with within-row hand weeding required 51.8 h ha^{-1} (Table 9). These weeding labor rates are much lower than reported elsewhere in the Sahelian zone, probably because of the unique use of the long handled hoe appropriate for millet cultivation in sandy soils. Because farmers normally weed within-row weeds while thinning the millet, adoption of the W_{a+h} method would seem uncomplicated. The use of donkeys for between-row

Table 8
Effect of pre-sowing tillage and weeding method on millet grain yield (kg ha^{-1}). Average of three seasons

Treatment	No-till	Ridge
Weeding method [a]		
W_0	31	73
W_a	128	339
W_{a+h}	602	775
W_f	717	778
SE [b]	34.4	

[a] W_0, no weeding; W_a, between-row weeding by animal traction; W_{a+h}, between-row weeding by animal traction plus additional within-row hand weeding; W_f, full field hand weeding.
[b] SE, standard error of means of treatments interaction.

Table 9
Seasonal weeding requirements (h ha^{-1}), average from 2 years, standard error in parentheses

Weeding method	First weeding	Second weeding	Total
Between-row cultivator	10.4 (1.01)	10.8 (2.02)	21.2 (2.30)
Within-row hand weeding	15.8 (2.83)	14.8 (1.73)	30.6 (3.27)
Full field hand weeding	39.0 (4.22)	31.1 (2.45)	70.1 (5.28)

cultivation reduced total weeding time by a modest 18.3 h ha^{-1}, but it could be important because the saving in labor time is accrued during the critical period for crop weed competition.

4. Conclusion

The amount of weeding in the crop was the single most important factor in controlling weed growth and, hence, in influencing crop yields.

In the mechanized between-row only method of weeding, within-row weed growth exceeded that of the weedy check, which resulted in unacceptable crop yield losses. However, pre-sowing ridging reduced the growth of within-row weeds in this case. Full field hand weeding, or the combination of between-row animal traction weeding and supplemental within-row weeding achieved similar, and adequate amounts of weed control. Hence, mechanized weeding with supplemental within-row weeding is recommended as the best combination for weed control in terms of crop yield.

Pre-sowing ridging reduced seasonal weed growth and produced higher pearl millet yields than cultivation without primary tillage. Seasonal weed growth did not increase during the three seasons of continuous millet cultivation.

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