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USE OF TINE-TILLAGE, WITH ATRAZINE WEED CONTROL, TO PERMIT EARLIER PLANTING OF MAIZE BY SMALLHOLDER FARMERS IN ZIMBABWE

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SUMMARY

Because of shortages of oxen for mouldboard ploughing, delayed planting of maize is common in Mangwende, Zimbabwe and reduces grain yield by 32%. On-farm experiments over four years tested the possibility of using a ripper tine, with atrazine herbicide, to allow smallholders to plant maize earlier. Compared to mouldboard ploughing, tine cultivation increased grain yield at 13 out of 18 sites. All these sites had less than 240 mm of rainfall in January (which coincided with crop anthesis) and long term rainfall records suggest tine cultivation should raise yields in two out of three years. Handweeding and atrazine treatments gave similar grain yields when used with tine cultivation, provided weeds were controlled within 14 days of crop emergence. Tine cultivation was economic at sites where the yield was greater than that with the mouldboard plough. The farmers could manage the combination of tine and atrazine use on a field scale.

Labranza con desgarradora dentada y uso de atrazine en fincas de reducido tamaño.

RESUMEN

Debido a la escasez de bueyes para arado mediante vertedera, con frecuencia se producen retrasos en la siembra de maíz en Mangwende, Zimbabwe, lo cual reduce el rendimiento del grano en un 32%. En experimentos llevados a cabo en fincas durante un período de cuatro años se analizó la posibilidad de utilizar una desgarradora dentada, junto con herbicida de atrazine, para permitir a los agricultores de fincas de menor tamaño una siembra más temprana del maíz. A comparación con la labranza mediante vertedera, el cultivo mediante desgarradora dentada incrementó el rendimiento de grano en 13 de los 18 fincas, todas las cuales recibieron menos de 240 mm de precipitaciones durante enero (lo cual coincide con la antesis del cultivo), y los registros de precipitaciones a largo plazo sugieren que el cultivo mediante desgarradora dentada incrementará el rendimiento en dos de cada tres años. Con la desgarradora dentada, la extracción manual de las malezas, y el uso de tratamiento con atrazine tuvieron por resultado un rendimiento de grano similar, siempre que el control de las malezas se efectuara dentro de un período de 14 días a partir de la emergencia del cultivo. El cultivo mediante desgarradora dentada resultó favorable desde el punto de vista económico en los sitios en que el rendimiento fue superior al obtenido mediante el uso de labranza por vertedera. Los agricultores pudieron manejar bien la combinación de desgarradora dentada y atrazine en la escala de sus tierras.

INTRODUCTION

It is well established in eastern and southern Africa that delayed planting of maize (*Zea mays*) after the onset of rains often results in reduced grain yields (e.g. Spear, 1968, and Weinmann, 1975, in Zimbabwe; Lungu, 1971, and MacColl, 1990, in Malawi). Such delays are especially lengthy in areas where smallholder farmers traditionally rely on the ox-drawn mouldboard plough for land preparation and oxen are in short supply. This is the case in much of Zimbabwe (Shumba, 1988). However, there has been little testing of technologies that might be used on smallholder farms to allow the earlier planting of maize and thus improve grain yields. Use of a ripper tine with atrazine weed control was proposed by Shumba (1984) as an appropriate technology for such farmers. Tine-tillage can reduce the draught power requirement for land preparation to as little as 14% of that of mouldboard ploughing (Willcocks, 1981) and yet maintain or increase grain yields of maize on sandy soils in Zimbabwe (Jones, 1973).

This paper reports the effects of tine-tillage and atrazine weed control on the grain yield of maize at Mangwende, a sub-humid communal area of Zimbabwe, and discusses the economic and other benefits for smallholders.

MATERIALS AND METHODS

Mangwende Communal Area (17°40'S, 31°40'E) is 60–90 km northeast of Harare. Maize is the dominant crop and occupied about 61% of the arable land in 1981/82. Annual rainfall is 800–1000 mm, all received between October and April. The area has infertile coarse-grained sandy loam Typic Kandiustalf soils, derived from granite.

Diagnosis of the late planted maize problem

Diagnostic surveys (Collinson, 1987) were conducted during 1982 to identify production problems the farmers faced with maize, including the problem of late planting. Thirty farmers were interviewed in an informal survey and 80 additional farmers (40 cattle owners and 40 non-owners) were interviewed in a formal survey. An exploratory experiment with three planting dates was carried out on four farmers' fields over three years (1983/84–1985/86) to verify the expected reduction in grain yield caused by delayed planting of maize. The average planting dates were 12 November, 2 December and 18 December. Full details of the methods used and results obtained from the surveys and the exploratory experiment have been reported by Shumba (1988 and 1989).

To allow oxen owners to plant maize earlier (by reducing the draught power required) it was decided to test an ox-drawn ripper tine, attached to the mouldboard plough beam. Owners would then be able to lend or hire their oxen to non-owners earlier. When interviewed, farmers were interested in the tine but predicted excessive early weed growth between crop rows, as has been reported to occur elsewhere in Zimbabwe (Jones, 1973). Farmers had a critical shortage of labour so that herbicide use was considered a better way to control the weeds resulting from tine tillage. Most of the common weeds in Mangwende, including *Richardia* species and *Acanthospermum hispidum*, are well controlled by the cheapest pre-emergence herbicide available, atrazine, and this was the one selected.

Experiment 1

This was carried out at seven farm sites during 1983/84 and 1984/85 using a split plot design with two replicates, to compare mouldboard ploughing (customary farmer practice) with tine planting as the main plot treatments. Hand weeding (farmer practice) and atrazine treatments were compared in the sub-plots. The tine was mounted on a standard mouldboard plough beam and drawn by two oxen to make soil furrows 90 cm apart and approximately 14 cm deep, into which seed and basal fertilizer were placed by hand and covered. Each plot consisted of eight rows, 90 cm apart and 10 m long. Planting was done simultaneously for both tillage treatments at each site. The atrazine treatment was applied as a 50% active ingredient formulation by previously trained cooperating farmers at a rate of 3.6 l ha^{-1} over the whole ground area using a knapsack sprayer, either at planting or at the one to two leaf stage of the crop. Hand weeding was done 15–30 days after crop emergence (normal farmer practice).

Non-treatment inputs and management were determined by individual co-operating farmers. The maize hybrids R215 or R201 were used. Planting dates averaged 18 November in 1983/84 and 8 November in 1984/85 and population densities of 37 000 to 42 000 plants per hectare were achieved. Basal fertilizer was applied at 30 kg N, 23 kg P and 21 kg K ha^{-1} at planting. In the tine treatment, the basal fertilizer was applied between planting stations in the tined furrow and covered. A single top dressing of 86 kg N ha^{-1} was given five to six weeks after planting. Daily rainfall records were collected by farmers from rain gauges placed at each site. Rainfall for the cropping season averaged 481 mm over all sites in 1983/84 and 684 mm in 1984/85.

Plots of 32.4 m^2 were harvested for grain yield (adjusted to 12.5% moisture). A combined analysis of variance for grain yield across sites was done. Partial budget methods were used to compare the economic returns of treatments (CIMMYT, 1988). Labour use was measured by estimating the time taken for a representative farmer to complete a task on a plot basis. After viewing the experiment, 76 farmers were asked their opinion on the tine and atrazine technology.

Experiment 2

This compared the yield effects of tine tillage and weed control with atrazine or two timings of hand weeding under more precise conditions in trials planted on 5 and 7 November 1986 at two farms in Mangwende. A split plot design with three replicates was used, with tillage method (ox-drawn tine or mouldboard plough) as the main plots and weed control (hand weeding at 30 and 60 days after crop emergence, hand weeding at 14 and 60 days, and post-emergence application of atrazine) as sub-plots. Plot size was 21.6 m^2, with four rows each 6 m long. All non-treatment management practices and inputs were at a high level using seed of cv. R215 planted at a spacing of 90 × 28 cm (39 683 seeds ha^{-1}). Basal fertilizer (30 kg N, 23 kg P and 22 kg K ha^{-1}) was applied at planting. Two top dressings each of 43 kg N ha^{-1} were applied at five and ten weeks after planting.

At one site (Musami), weeds were harvested, dried and weighed from plots of two rows, each 1 m long, 21 days after crop emergence. At harvest, grain yield (corrected to 12.5% moisture) was measured on net plots of 7.2 m^2.

Experiment 3

This compared the benefits from the tine and atrazine combination with the current farmer practice of mouldboard ploughing and hand weeding, using large 0.4 ha plots under current farmer inputs and management. The experiment was planted on two farms in 1987/88 without replication at a site. Plots of the tine and atrazine combination under farmer inputs and management were compared with the farmers' adjacent crops of maize that had been grown using a mouldboard plough and hand weeding. Cooperating farmers were supplied with the tine and atrazine but provided all other maize production inputs and determined their management. Farmers maintained a record of their actions. Well bordered plots of 86.4 m^2 were harvested for grain yield.

RESULTS

Data from the 1982 formal survey had shown a linear regression of grain yields on planting date, suggesting that delays in the first maize planting over the period 5 October to mid-December reduced yields by 1.35% per day ($Y = 4.43 - 0.06t$, $r^2 = -0.63$, $P < 0.001$, where Y is grain yield in t ha^{-1} and t is the date of sowing in days after 5 October). These results were confirmed in the exploratory experiment (Shumba, 1989) and the results agreed well with earlier work by Spear (1968) in Zimbabwe where yield was reduced by 1–3% per day of delay in planting after mid-November. In 1981/82, 41% of farmers planted more than 21 days after the first planting rains. They were aware of the yield loss caused by delayed planting, but said that shortage of oxen draught power was the major cause of the delays.

The formal survey showed that 54% of farmers in Mangwende did not own oxen but borrowed or hired them for seedbed preparation. Farmers who owned oxen had better and more timely seedbed preparation and so planted earlier and achieved average maize yields of 3.24 t ha^{-1} compared with 2.1 t ha^{-1} for non-owners.

Experiment 1

There was a significant site × tillage interaction ($P < 0.001$) for grain yield over the two years. The plots with tine tillage outyielded the mouldboard plough plots at all seven sites in 1983/84, with a significant yield increase ($P < 0.05$) at four

Table 1. *Effect of ripper tine and mouldboard plough tillage on maize grain yield (t ha^{-1}) at seven on-farm sites, Experiment 1, 1983/84 and 1984/85*

	On-farm site						
	1	2	3	4	5	6	7
			1983/84				
Ripper tine	1.53	5.21	4.95	2.83	7.20	5.28	2.97
Mouldboard plough	1.19	3.26	4.35	2.68	5.82	4.61	1.99
SE	0.26	0.23	0.12	0.08	0.04	0.13	0.09
			1984/85				
Ripper tine	7.14	4.04	5.24	6.63	6.85	2.18	5.36
Mouldboard plough	5.89	3.56	6.07	7.63	7.25	2.49	6.62
SE	0.18	0.07	0.09	0.14	0.16	0.09	0.48

sites, but lowered yields at five of the seven sites in 1984/85 (Table 1). Tine cultivation raised grain yield by an average of 0.86 t ha^{-1} (23%) at nine sites and reduced it by 0.75 t ha^{-1} (12%) at five sites.

To help explain the site × tillage interaction, sites were grouped into those showing a grain yield increase or decrease with tine tillage (Matlon, 1984). Positive or negative yield effects were then regressed on the following non-treatment variables measured at each site: soil pH, soil phosphorus, soil nitrogen, planting date, maize variety, winter ploughing, and rainfall received in November, December, January, February and over the whole crop growth cycle. Among these variables, January rainfall explained most of the variability in grain yield response to tine tillage across the sites and years ($r^2 = 0.76$) (Fig. 1). Tine tillage increased yields at sites that received less than 240 mm of rainfall in January and depressed yields at those sites that received more than 240 mm. Dates of 50% anthesis ranged between early and late January across the trial sites, suggesting that maize yield response to tine tillage depended on the amount of rainfall that fell within 10 to 15 days of tasseling.

Agronomic performance of atrazine. There was good control of weeds at all sites in both years by both hand weeding and atrazine. Method of weed control did not affect maize grain yield in either tillage treatment, although weed growth before the first hand weeding was more vigorous after tine tillage than after the mouldboard plough. Weeds emerged before or with the crop in the tine treatment, but emerged after the crop with the mouldboard.

Economic evaluation of tine and atrazine. The net benefits from the tillage and weed control treatments at the nine out of 14 sites where tine tillage increased grain yield, i.e., sites with less than 240 mm of rainfall in January, are shown in Table 2.

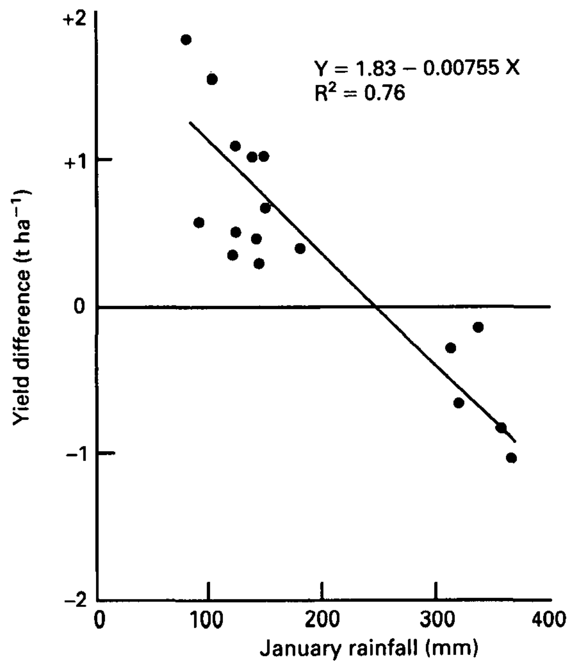

Fig. 1. Relationship of the yield difference between the two tillage systems (maize grain yield with tine tillage minus yield with mouldboard tillage) with January rainfall, 1983/84 to 1987/88.

Tine tillage with atrazine gave the best net benefit while the yield advantage of the tine cultivated and hand weeded treatment was offset by the high weeding costs, which were 4.5 times the cost of herbicide use. But at the remaining five sites where the tine reduced yields, a switch to the tine would have resulted in savings

Table 2. *Economic evaluation of the tillage and weed control treatments in Experiment 1 at sites where tine tillage raised grain yields (i.e. where January rainfall was less than 240 mm)*

	Hand weeding		Atrazine	
	Mouldboard	Tine	Mouldboard	Tine
Adjusted yield (t ha^{-1})†	2.86	3.53	3.07	3.78
Gross benefit (Zim$ ha^{-1})	378	466	405	499
Cash costs (Zim$ ha^{-1})				
Sprayer	0	0	8	8
Herbicide	0	0	17	17
Seedbed preparation	34	17	34	17
Cost of capital‡	13	7	23	16
Labour time costs (Zim$ ha^{-1})§				
Planting and fertilizer application	22	11	22	11
Handweeding	80	161	0	0
Herbicide application	0	0	11	11
Total variable costs (Zim$ ha^{-1})	149	196	115	80
Net benefit (Zim$ ha^{-1})	229	270	290	419

†At 12.5% moisture, less 20%. ‡40% per year. §Zim$ 0.44 $hour^{-1}$.
All costs are for 1987, when the exchange rate was 1 Zim$ = US$ 0.50.

Table 3. *The effect of weeding method and tillage method on maize grain yield (t ha^{-1}) and weed biomass (kg m^{-2}) three weeks after crop emergence, Experiment 2, 1986/87*

	Grain yield	Weed biomass
Weeding method		
Hand weeded at 30 and 60 days	3.75	4.21
Hand weeded at 14 and 60 days	4.66	0.92
Atrazine application	4.40	0.58
SE	0.13	0.36
Tillage method		
Tine	4.55	2.65
Mouldboard plough	3.99	1.15
SE	0.11	0.40

in cash or labour that were just insufficient to offset the reduced net benefits, even when atrazine was used. Net benefits at the sites were 616, 481, 680 and 644 Zim$ ha^{-1} for tine with atrazine, tine with hand weeding, mouldboard with atrazine and mouldboard with hand weeding treatments, respectively.

Experiment 2

On average the tine tilled plots yielded 14% more than mouldboard plough plots ($P < 0.01$). Rainfall in January was less than 240 mm and the relationship with rainfall was similar to that in Experiment 1. As expected, mouldboard ploughed plots had less weed biomass three weeks after crop emergence than those with tine tillage ($P < 0.05$). Hand weeding at 30 days (farmers' normal practice) gave a smaller ($P < 0.05$) grain yield than hand weeding at 14 days or atrazine application (Table 3). There was a negative correlation ($r^2 = -0.5$; $P < 0.001$) between maize grain yield and weed biomass suggesting that weed competition in the 30 day hand weeding treatment was responsible for part of the reduction in grain yield.

Experiment 3

The treatments performed in a similar way at the two sites. The tine and atrazine combination gave an average grain yield of 5.43 t ha^{-1} compared with 4.30 t ha^{-1} for the mouldboard plough and hand weeding combination ($P < 0.05$), an increase of 26%. Both sites received less than 240 mm rainfall in January. The larger yield increase over current farmer practice than in the previous experiments was probably the result of the basal fertilizer application at planting, and first weeding (with atrazine) five days after planting compared with 21 days after crop emergence for hand weeding.

Farmer assessment of the tine and atrazine technology

Most farmers surveyed were pleased with the tine and atrazine treatment. Thirteen of the 20 non-cattle owners felt the tine would allow earlier establishment of their maize crops and most farmers thought that it would reduce draught power hire charges to about 45% of those for mouldboard ploughing. Fifty-two of the 76 interviewed farmers said the tine would increase maize yields, 17 thought it would have no effect and nine said it would reduce yield. Twenty-seven farmers showed interest in adopting the tine in future cropping seasons. However, intention to adopt the tine was linked to previous experience with herbicide, in that 15 of the 33 farmers who had previously used herbicides were keen to use the tine again compared with only 11 of the 43 farmers with no previous herbicide experience.

DISCUSSION

From the results it appears that tine tillage, compared to the mouldboard plough, will improve maize grain yields by up to 26% (with early weeding) in fields that receive less than 240 mm of rainfall in January, i.e., when crop anthesis coincides with a relatively dry period. During the period of the experiments this occurred at 13 of the 18 sites where tine tillage was tested, but unfortunately January rainfall is an unpredictable feature of a given year and site and a site with a low January rainfall in one year may have a high rainfall in the next. An examination of rainfall amounts in January at Mangwende over a 39 year period (1950/51–1988/89) showed that January rainfall was below 240 mm in 25 out of 39 years. Thus in almost two out of three years the tine should improve grain yields of maize in Mangwende and in other cases the yield reductions should not be large.

Given the relationship between yield performance of the tine and rainfall in January, experiments are underway to determine long term (five year) effects of tine tillage on the hydrological properties of the soil and on soil bulk density (compaction) in relation to grain yield. The yield increases with tine tillage at the sites with low January rainfall were probably due to increased soil moisture availability, while the poorer yields at the wetter sites might have resulted from more soil pore space being filled with water, resulting in anaerobic conditions (Linn and Doran, 1984).

Atrazine gave no grain yield benefit over hand weeding in Experiment 1, probably because cooperating farmers hand weeded earlier than expected (around 14 days post-emergence), whereas farmers' normal practice is to weed at around 30 days post-emergence. This explanation was confirmed by Experiment 2, where hand weeding at 30 days resulted in smaller yields than atrazine use or hand weeding at 14 days (Table 3). These results show that, provided a farmer has sufficient labour to weed early, there is unlikely to be a yield incentive to change from hand weeding to herbicide use. But most farmers have insufficient labour and the main benefit of atrazine use will be to release labour for timely weeding rather than to increase the maize yield directly. The heavier and earlier weed burden seen in tine-tilled plots in Experiment 2 confirmed farmer concerns that weed infestation is a major problem with tine tillage. Full yield benefits from the tine will depend on it being used with atrazine.

Cropping system benefits and adoption potential of the tine and atrazine combination

The reduced draught power and labour requirements make the tine and atrazine combination an appropriate technology for Mangwende farmers. Cattle owners appreciated the advantage of the reduced draught burden, in enabling earlier planting. Just how much earlier non-owners would have access to draught power following adoption of the tine by owners cannot be tested until cattle owners adopt the tine.

Experiment 3 showed that use of the tine and atrazine combination was manageable by farmers with their current inputs. However, cash-poor farmers might find the tine cultivation unattractive because of the cost of atrazine or the increased labour requirements for hand weeding if herbicide is not used.

In conclusion, these results suggest that if employed together, the tine and atrazine technology would reduce the oxen requirement and thus reduce late planting of maize in Mangwende and increase maize productivity for both owners and non-owners of cattle.

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