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The Need for Integrated Weed Management Systems in Smallholder Conservation Farming in Zimbabwe

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1 Introduction

This paper reports the results of the last two seasons (1992-93 and 1993-94) of a six-year (commencing in 1988-89) on-station study comparing conventional tillage to four conservation tillage techniques. Emphasis was on the weed biomass production and resulting labour requirements for hoe weeding for the various tillage treatments over this period of two years and on a herbicide trial with Roundup Dry (glyphosate) preseeding applications during the last (1993-94) season. Although hoe weeding still constitutes the major means of weed control in smallholder conservation farming in Africa (LAL, 1986), various studies have shown that reduced levels of (pre-emergence) herbicides followed by one or two cultivations can efficiently control weeds during the growing season thereby providing for yields similar to those obtained with purely chemical weed control while, at the same time, reducing labour input considerably (ROBISON and WITTMUSS, 1973; GWORGWOR and LAGOKE, 1992; BUHLER et al., 1992, 1994).

Although it is generally accepted that the non-disturbance of the soil with conservation tillage based on herbicides helps exhaust annual weed seed reserves (SCHWEIZER and ZIMDAHL, 1984a; 1984b), perennial weed species are bound to increase (TRIPLETT and LYTLE, 1972; BORLAND, 1980). Results for the first four years of these tillage trials corroborate this hypothesis. All four conservation tillage techniques quickly developed a severe perennial-weed problem (VOGEL, 1994). The acceptance of conservation tillage systems thus generally revolves largely around perennial weed control (TRIPLETT and WORSHAM, 1986). However, in these trials, conventional tillage produced similarly high biomass of annual weeds during the growing season and, as a result, traditional hoe weeding proved very labour intensive no matter whether conservation or conventional tillage was practised. Because labour is a production constraint in Zimbabwe's smallholder farming sector, on-going trials of testing alternative methods of weed management were initiated. They involve simple look-and-see trials on new mechanical weeders and on strip cropping as well as the herbicide experiment described in this study.

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2 Methods and Materials

The study site is located at Domboshawa Training Centre in northern Zimbabwe at an altitude of 1550 m above sea level and a long-term (50-years mean) average annual rainfall of 880 mm (ANDERSON et al., 1993). Soils at the site are granite-derived sands featuring very low water-holding and cation-exchange capacities and often gleyic properties (VOGEL, 1992).

Five tillage systems (conventional mouldboard ploughing, ripping into mulch, ripping into bare ground, no-till tied ridging, and badza holing-out (traditional hand hoeing)) were tested under continuous maize (*Zea mays* L.) monoculture (VOGEL, 1994). Two weed experiments were carried out. The first experiment to study weed biomass production and hoe-weeding labour requirements for all five tillage treatments had been on-going since 1989-90 (labour time) and 1990-91 (weed biomass) respectively (VOGEL, 1994). It was conducted on plots measuring 20 m x 35 m, or in the case of no-till tied ridging 8 m x 160 m. The experimental design was a randomized complete block with three replications for each tillage treatment.

The second experiment to study the optimal application levels of glyphosate was carried out during the 1993-94 season on plots measuring 6 m x 18 m with a split-plot treatment arrangement. Tillage treatments were the whole plots and herbicide treatments were the subplots. Individual herbicide-subplots were 6 m x 6 m and each treatment was randomized in a complete block and replicated four times. Four similar hoe-weeded control plots of 6 m x 18 m size were included for comparison, one in each of the four blocks. In the herbicide experiment, only three tillage treatments were compared to each other, namely conventional tillage, tied ridging, and clean ripping. Three different preseeding applications (1.1, 2.2, and 3.3 kg ai ha-1 respectively) of the dry Roundup formulation (130-g-sachets containing 42% active ingredient) of glyphosate [*N*-(phosphonomethyl)glycine] were sprayed broadcast employing a standard 15-L-knapsack sprayer fitted with a low-volume nozzle (AN 1 Lurmark) delivering 100 L ha-1 of spray solution. The three dosage rates were selected on the basis of their likely performance and cost. In order to avoid herbicide drift within each split-plot a portable plastic screen was used. All spraying took place on 18 November 1993 in calm[1] and fine[2] weather conditions.

Weed biomass collections were carried out in both experiments by harvesting weeds from 1 m x 1 m squares that were placed at equal distance along a diagonal line on each plot (three samples were taken from each of the bigger plots of experiment one and two samples from each (sub-)plot of experiment two). The weed samples were later averaged to obtain a plot mean. The weed dry weights were obtained after drying in an oven at 105°C for 16h. In addition, weed ground cover developments were

[1] Daily wind speed: 21 (max), 0.8 (min), and 9.9 (mean) km/h respectively

[2] Daily humidity: 88 (max), 35 (min), and 60.5 (mean) % respectively; daily temperature: 22 (max), 10 (min), and 16 (mean) °C respectively

observed in the second (herbicide) experiment for a period of two months, that is from the time of spraying and initial hoe-weeding of the check plots (18 November 1993) respectively, until second within-season hoe weeding (12 January 1994) of all plots. For this, weed ground cover was monitored weekly at three randomly selected spots within each sub-plot employing a sighting frame (ELWELL and WENDELAAR, 1977).

All weed and maize yield data were subjected to analysis of variance. The data for the first weed experiment were analyzed as an ordinary randomized complete block design, and least significance difference (LSD) was used to compare tillage treatment means. Data for the second experiment were analyzed both as a split-plot as well as a randomized block design; however, because the field layout of the herbicide experiment contained hoe-checks which had not been split, the analyses for the randomized block design appeared more appropriate. In the case of the herbicide experiment, treatment means were compared on the basis of the one-tailed test using a critical t-value of 1.684 for statistically significant difference. In both weed experiments, individual treatments were compared with each other only if the treatment effect was significant at the 5% probability level.

The look-and-see trials involved the testing of a donkey-drawn blade weeder (DITGES, 1992) and a wheeled hand-pushed blade weeder (IAE, 1993a), and the implementation of no-till strip cropping (ELWELL, 1990). The cropping pattern with the latter was 70% maize, 20% soya beans (*Glycine max* (L.) Merr.), and 10% finger millet (*Eleusine coracan* (L.) Gaertn.). Maize was underplanted either with pumpkins (*Cucurbita spp.*), cowpeas (*Vigna spp. unguiculata*) or bonavist beans (*Dolichos lablab* L.).

3 Results and Discussion

Results for the first four years (1988-89 to 1991-92) of the trial prior to this study had revealed that all four conservation tillage techniques under investigation increasingly suffered from perennial weed infestation (VOGEL, 1994). The most troublesome weed present was Mexican clover (*Richardia scabra* L.) followed by Couch grass (*Cynodon dactylon* (L.) Pers.). Proliferation of these weeds, in particular Mexican clover, has become even worse since then.

Mexican clover (synonyms: Florida purslane, Florida pursley) is a much-branched, creeping, broad-leaved herb of the Rubiaceae family (BISWAS et al., 1975). It has been reported mostly for sandy soils (RICHARDS et al., 1978; BRIDGES and STEPHENSON, 1991). Introduced from tropical America it is now a widespread problem weed in Zimbabwe (DRUMMOND, 1984). It resembles *Richardia brasiliensis* (Moq.) Gomez deceivingly, which, in Zimbabwe, occurs in the same sandy-soil habitats. At Domboshawa, its persistence has been found to stem largely from long tap roots growing to depths deeper than 1 m (VOGEL, 1994) thus even penetrating the otherwise root-growth limiting stone line present in all soil profiles

(VOGEL, 1992). It flowers throughout the year and hence provides for an enormous number of seeds at or near the soil surface. The seeds lack innate dormancy and have been found to germinate equally well in the entire pH range of 3 to 8, but only if situated in the top 15 mm of the soil (BISWAS et al., 1975). From the latter findings and the experience gained at Domboshawa, it is to be expected that the active weed seed reservoir of Mexican clover would decrease rapidly if seeds were buried at greater depth through tillage operations.

3.1 Weed biomass production, consequent hoe weeding requirements, and crop yields

The across-years analysis of variance revealed that there was a highly significant ($P = 0.016$) seasonal effect on weed biomass production which is considered to have been due to similarly variable seasonal rainfall totals and distribution (Figure 1a and 1b). Equally significant were the effects of block, weeding run, and treatment on weed biomass while the treatment x weeding run interaction was statistically insignificant. The within-years analyses of variance confirmed the across-years analysis of variance with regard to the highly significant effects of block, weeding run, and treatment on weed biomass production while the treatment x weeding run interaction was, again, not significant (Table 1). The weeding run x treatment interaction was, however, significant for weeding time (Table 1). Although weeding was done on a piece-work basis in order to optimize equal labour input, the differences in weeding time between tillage treatments are bound to be variable for different weeding runs; firstly, since not always the same women were employed and, secondly, because even the same person is unlikely to always work or be able to work in the same way. However, the significant weeding run x treatment interaction rendered treatment comparisons with regards to seasonal labour totals inappropriate. Consequently, tillage treatments were only compared statistically for individual weeding runs with regard to weeding time.

Prior to the 1992-93 growing season, that is 14 days before planting (DBP), perennial weed biomass ranging from just over 200 kg ha^{-1} for mulch ripping to nearly 1200 kg ha^{-1} for clean ripping were recorded, while conventional tillage had a mere 6 kg ha^{-1} (Figure 2a). As a result, all the conservation tillage treatments required a first hoe weeding 8 DBP the maize crop for the 1992-93 growing season (Figure 2c). During the subsequent (1993) dry season, Mexican clover even invaded the field plots of the conventional till treatment. By the beginning of the sixth (1993-94) consecutive trial season, Mexican clover had thus established itself in the field plots of all five tillage treatments under investigation. Huge circular plants of this species, frequently featuring diameters of 1 m, contributed to an enormous weed biomass of 1542 kg ha^{-1} for conventional tillage (as recorded 10 DBP) which was only slightly less than the 1592 kg ha^{-1} observed for clean ripping (Figure 2b). Clean ripping was the only treatment infested mainly by Couch grass. As a result of Mexican clover almost covering whole conventionally-tilled field plots, these plots also needed to be hoe weeded prior to sowing in early November 1993 (Figure 2d).

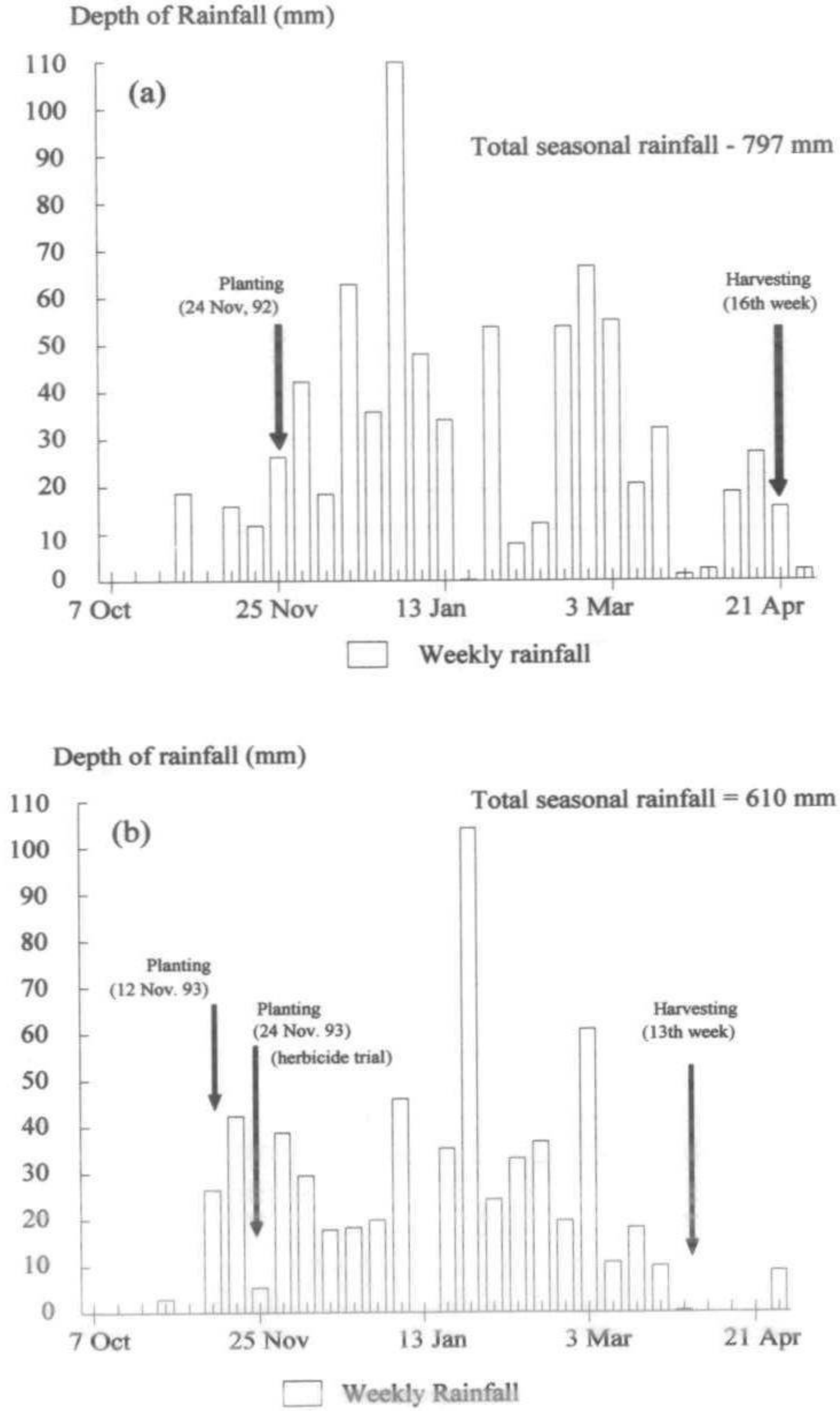


Figure 1: Weekly rainfall totals and distribution during the (a) 1992-93 and (b) 1993-94 rainfall/growing seasons at Domboshawa, Zimbabwe.

This constituted an unexpected precedent for the entire six-year trial period. Over the two seasons, clean ripping had the highest infestations ranging from 4620 kg ha^{-1} in 1992-93 to 5650 kg ha^{-1} in 1993-94 (cf. Figures 2a and 2b). Clean ripping was followed in weed infestation by badza holing-out which produced 4120 kg ha^{-1} of weeds in 1992-93 and 4850 kg ha^{-1} in 1993-94. Conventional tillage occupied an intermediate position yielding 3750 kg ha^{-1} in 1992-93 and 4550 kg ha^{-1} in 1993-94. Mulch ripping featured the second lowest weed biomass production in 1992-93 (2476 kg ha^{-1}), but the second highest (5000 kg ha^{-1}) during the 1993-94 season which suffered from late-season drought. Tied ridging produced fewest weeds in both years ranging from 1950 kg ha^{-1} in 1992-93 to 2350 kg ha^{-1} in 1993-94.

Table 1: Probabilities of factor effects on weed biomass and weeding time for two growing seasons (1992-93 and 1993-94) at Domboshawa, Zimbabwe.

Fraction Probabilities				
	Weed biomass		Weeding time	
Source:	*1992-93*	*1993-4*	*1992-93*	*1993-94*
Block	0.004	0.000	0.001	0.000
Weeding run	0.000	0.007	0.000	0.000
Treatment	0.026	0.031	0.000	0.000
Run x treat	0.284	0.317	0.000	0.002

Due to the extra preplanting weeding run as well as the overall worsening weed problem, total seasonal labour requirements for hoe weeding increased dramatically for most treatments from a previous level of approximately 300 to 400 h ha^{-1} (VOGEL, 1994) to up to 800 h ha^{-1} for clean ripping (cf. Figures 2c and 2d). Rather contradictory was the situation for mulch ripping. Although the between-row application of maize residues helped suppress perennial weed growth, it nevertheless contributed to high seasonal hoe-weeding labour times (600-700 h ha^{-1}) as had been observed at this site (VOGEL, 1994) and similar farming environments (LAMERS and FEIL, 1993) before. Badza holing-out featured the same seasonal levels of weeding time as mulch ripping while conventional tillage was lower at 360 h ha^{-1} (1992-93) and 420 h ha^{-1} (1993-94) respectively. The smallest increase was for tied ridging which experienced a rise in hoe-weeding labour requirements from a previously recorded average of 290 h ha^{-1} to 340 h ha^{-1} in 1993-94. Conventional tillage and tied ridging both benefited significantly from mechanical weeding after harvesting (Figures 2c and 2d).

TABLE 2: Maize yield components and yield levels as affected by tillage and year at Domboshawa, Zimbabwe.[3]

Season	Rain (mm)	Tillage system	Population at harvest	Prolicacy (cobs/pl)	Grain per cob (g)	Grain yeild[4] (Kg/ha)	Stover yield[5] (Kg/ha)
1992-3	797	Convent .tillage	34848	1.00	138a	4596a	2430a
		Clean ripping	30862	1.03	150ab	4617a	2092a
Planting Date:		Mulch ripping	29366	1.05	135a	3861a	2575a
24 Nov. 1992		Hand hoeing	34648	1.00	185b	6408b	3016a
		Tied ridging	35692	1.00	180b	6359b	4668b
1993-4	610	Convent .tillage	37470	0.98	125	4591	3211
		Clean ripping	33975	1.01	159	5511	2938
Planting Date:		Mulch ripping	33555	1.01	167	5687	3467
12 Nov. 1993		Hand hoeing	39757	1.04	170	7009	3848
		Tied ridging	34846	1.04	166	5953	4200

The common weed pattern after removing perennials was one of rapid and intense emergence of annual weeds within the first 20 days after planting (DAP). This is clearly reflected by the highest weed biomass production at the time of second weeding, that is the first weeding after sowing (Figures 2a and 2b). At this stage, however, weed biomass values were so highly variable in both years that the treatment effect was statistically insignificant. Similar tendencies of the variance to increase with increasing weed biomass production had been observed in these (VOGEL, 1994) and other trials (FORCELLA and LINDSTROM, 1988) before.

Because of the general intense early-emergence pattern of annual weeds (Buhler, 1992), strong competition with young maize plants arises (MULUGETTA et al., 1989), on the experimental sandy soils in particular for moisture (VOGEL, 1994).

[3] Means followed by the same letter are not significantly different at $P < 0.05$.

[4] 12.5% moisture content

[5] Dry matter

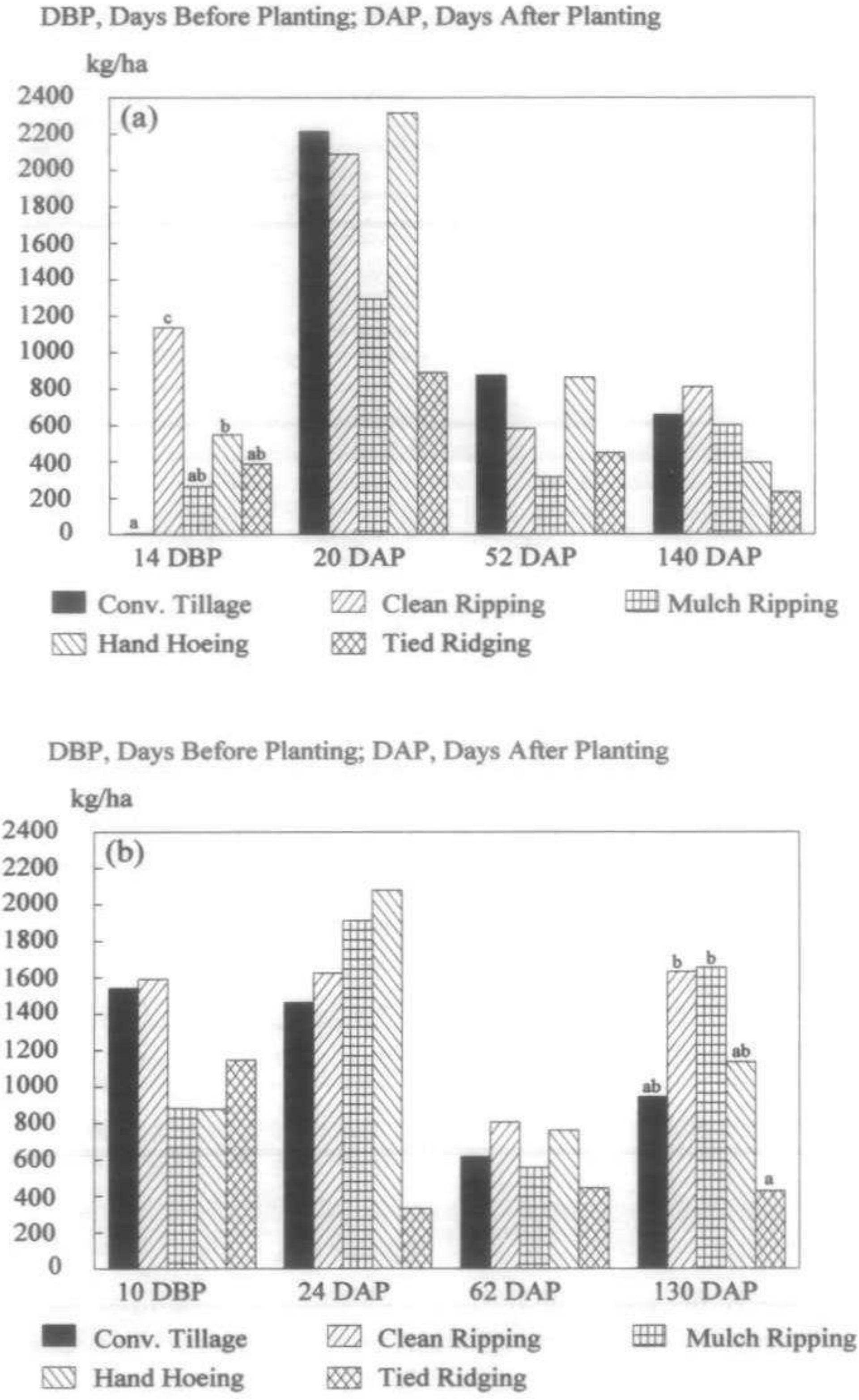
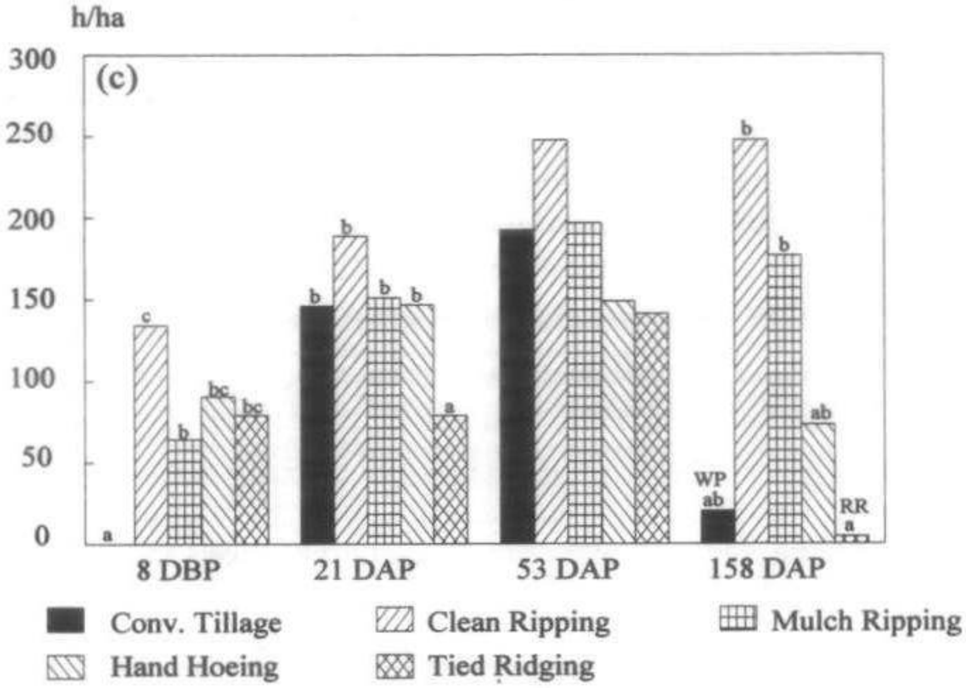


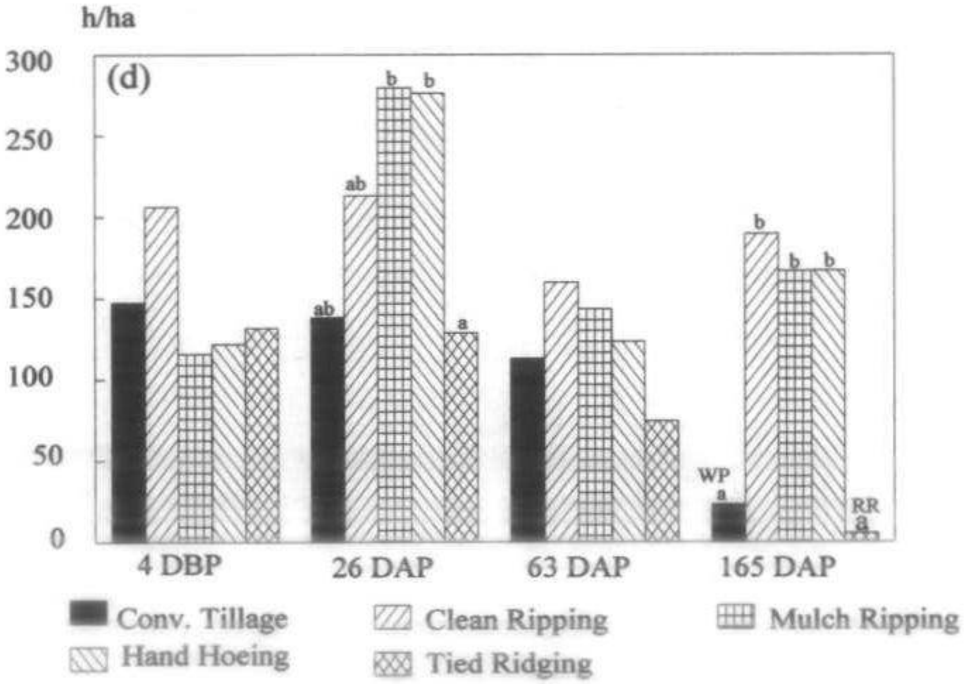
Figure 2: Dry weed biomass production over two growing seasons at Domboshawa, Zimbabwe, as affected by tillage, (a) 1992-93 and (b) 1993-94. Treatments with the same letter(s) are not significantly different based on LSD ($P < 0.05$).

DBP, Days Before Planting; DAP, Days After Planting



WP, Winter Ploughing; RR, Re-Ridging

DBP, Days Before Planting; DAP, Days After Planting



WP, Winter Ploughing; RR, Re-Ridging

Figure 2: Resultant hoe weeding labour requirements from dry weed biomass production over two growing seasons at Domboshawa, Zimbabwe (c) 1992-93, and (d) 1993-94. Treatments with the same letter(s) are not significantly different based on LSD ($P < 0.05$).

Hence, the early flush of annual weeds was removed within four weeks after planting in both years (Figures 2c and 2d). This timely weed management helped produce consistently high treatment yields in the order of 4-6 t ha^{-1} of maize grain (Table 2). Such high grain yield levels must be considered excellent for granitic sands (GRANT, 1981); even more so for the last 1993-94 season which experienced a severe late-season drought limiting total seasonal rainfall to only 610 mm (Figure 1b). In fact, the last (1993-94) season produced the overall highest grain yield levels over the six-year trial period which must be attributed, at least partly, to the earliest ever planting (12 November 1993) during this period of six years.

3.2 Mechanical weed control

Although hoe weeding is the most common method of weed control in smallholder farming in Zimbabwe, results of this study showed that it is not only highly labour-intensive but also inefficient for controlling perennial weeds. In addition, it frequently leads to crop damage due to maize root pruning. Consequently, less reliance on hoe weeding is desirable. Two years of testing a donkey-pulled blade weeder[4] (DITGES, 1992) showed that labour time requirements for between-row weeding can be reduced to between approximately 15 to 25 h ha^{-1} per weeding run, depending partly on weed density. Since the implement, in its present design (width = 60 cm), does not cover the standard maize crop width of 90 cm, two passes were often required for every pair of maize rows. If weed cover was dense, then the implement clogged quickly necessitating frequent clearing stops. It also tended to drag along robust weeds rather than to cut them, in particular the spreading Mexican clover and Couch grass plants. In all these situations, implement-pulling proved very tiring for both the operator and the donkey. As a consequence, weeding employing the donkey-pulled blade weeder needs to be done early when weeds are still small in size and numbers. Its weeding efficiency was poorer than for the locally available Zimplow tine cultivator. Generally, the weeding efficiency of the donkey-pulled blade weeder was 83% compared to 94% for the 5-tine (width = 70 cm) Zimplow cultivator (Moyo, 1994). However, the implement reduced draught force from approximately 1.2 kN as measured for the Zimplow cultivator (1714 N/m) to approximately 0.6 kN (1000 N/m) (MOYO, 1994). Thus it allowed for the employment of a single donkey while the alternative Zimplow cultivator required a team of oxen (Appendix). Considering that weeding is a woman's task and that donkeys are not only easier to train and handle than oxen but also cheaper (IAE, 1993b; HAGMANN and PRASAD, 1994), this cultivator may be particularly appropriate for smallholder farmers. With respect to the above time requirements (15 to 25 h ha^{-1}), it should be noted that they do not include the additional time required for in-row hoe weeding. Results of a complementary research programme indicate that the labour required for the additional in-row hoe weeding varies from approximately 20-60 h ha^{-1}, that is

[4] Featuring a sweep tine in the front trailored by two outlying angle-blades thus forming a triangular body

in-row hoe-weeding tends to double or even triple the time required for animal-drawn cultivation only (CHATIZWA and VORAGE, 1993). Yet, the combined data indicate that combining animal-drawn cultivation and manual weeding reduces labour per weeding run by at least 25%, and up to 75%, compared to pure hoe weeding (Figures 2c and 2d). Similar findings have recently been reported for other research in Zimbabwe (DHLIWAYO et al., 1994).

The hand-pushed blade weeder (IAE, 1993a) tested had similar advantages as well as disadvantages to the donkey-pulled blade weeder. It reduced labour time requirements in combination with the hoe (for in-row weeding) by approximately 10-15% compared to pure hoe-weeding only, while its weeding efficiency was 72% compared to 81% for the traditional hoe (CHATIZWA and RAINBIRD, 1994). Like the donkey-pulled blade weeder, it also tended to congest quickly in the presence of strong weed infestation. Farmers have, however, expressed interest in testing both the donkey-pulled and the hand-pushed blade weeder on their fields. Consequently, testing has been initiated as part of the project's adaptive on-farm trial programme. This testing programme also involves a 45-cm-wide sweep-tine cultivator which is attachable to the mouldboard plough beam. A great advantage of all these implements is that they can be manufactured from scrap material by rural blacksmiths. Hence, appropriate tool-making has been included in rural technology training courses (MUPFAWA, 1991).

3.3 Preseeding glyphosate application

While mechanical weed control is one of the main reason put forward for using conventional tillage (ARSHAD et al., 1994), herbicides have made the adoption of conservation tillage practices possible on a large scale (TRIPLETT and LYTLE, 1972; BORLAND, 1980). However, previous research also suggests that reduced rates of pre-emergence herbicides to suppress weeds early in the growing season followed by one or two inter-row cultivations after planting to control annual weeds may be an effective and economically sound weed management option for maize planted into untilled soil infested with perennial weeds (GWORGWOR and LAGOKE, 1992; BUHLER et al., 1992, 1994). In particular glyphosate has proven to effectively control many noxious weeds including Mexican clover and Couch grass; although season-long only in combination or sequence with other herbicides (ARNOLD and ALDRICH, 1979; BROWN and WHITWELL, 1985; THOMAS, 1986; GIPS, 1987; BRIDGES and STEPHENSON, 1991). Glyphosate is a non selective systemic herbicide that is readily absorbed by actively-growing leaves and translocated throughout the plant (MONSANTO, 1992). Glyphosate has very low toxicity to humans and degrades fairly rapidly due to an average half-life of usually less than 60 days (ASHTON and MONACO, 1991). It is strongly bound to soil colloidal matter and hence leaching into the groundwater is limited; an aspect, which is particularly important for the sandy soils most common in Zimbabwe's smallholder farming sector. The tested dry formulation is available in convenient sized packs (130-g-sachets) that are easily distributed; again, an aspect which is of particular importance for smallholder farmers (PARKER, 1983).

On 18 November 1993, glyphosate dry formulation was applied in three dosage rates (1.1., 2.2., and 3.3. kg ai ha^{-1}) preseeding on a well-established stand of mainly Mexican clover and Couch grass which had grown throughout the dry winter season (May-October). At the same day, the four check plots were hoe weeded. On 13 December 1993, and again on 11 January 1994, all plots were hoe weeded to eradicate annual weeds which had emerged soon after planting and those perennials that had escaped glyphosate application and/or hoe weeding. Statistical data analyses revealed that the tillage x weeding interaction was not significant throughout, that is clean ripping, conventional tillage, and tied ridging responded similarly to all four weeding treatments. This was the case for weekly weed ground cover developments (Figures 3a-3c) as well as for weed biomass production and maize yields. Hence, the data was pooled (the tillage x weeding interaction and error variability was averaged over the degrees of freedom) in order to improve the efficiency of the tests. The results showed that the effect of tillage treatment, weeding treatment, and block on weed biomass production was highly significant for all three dates investigated, except for the block effect on 13 December 1993 (Table 3). Tied ridging produced significantly the lowest weed biomass at all three dates (Table 4) and, at the end of the season, recorded significantly the highest maize grain and stover yields (Table 5). Although conventional tillage produced significantly less weeds in mid-season (11 January 1994) and at the end of the season (21 March 1994) than clean ripping, it did not yield more maize grain and stover than clean ripping. With regards to ridging, the results indicate that ridging enhanced the level of weed control of all weeding treatments. This appears mainly attributable to better shading provided by the observed generally better maize stands on ridges (VOGEL, 1993), and also to the supplemental cultivation used to re-form the ridges (AKINYEMIJU and ECHENDU, 1987; BUHLER, 1992; NYAGUMBO, 1993).

Table 3: Probabilities of factor effects on weed biomass in the herbicide trial at three dates during the 1993-94 growing season at Domboshawa, Zimbabwe.

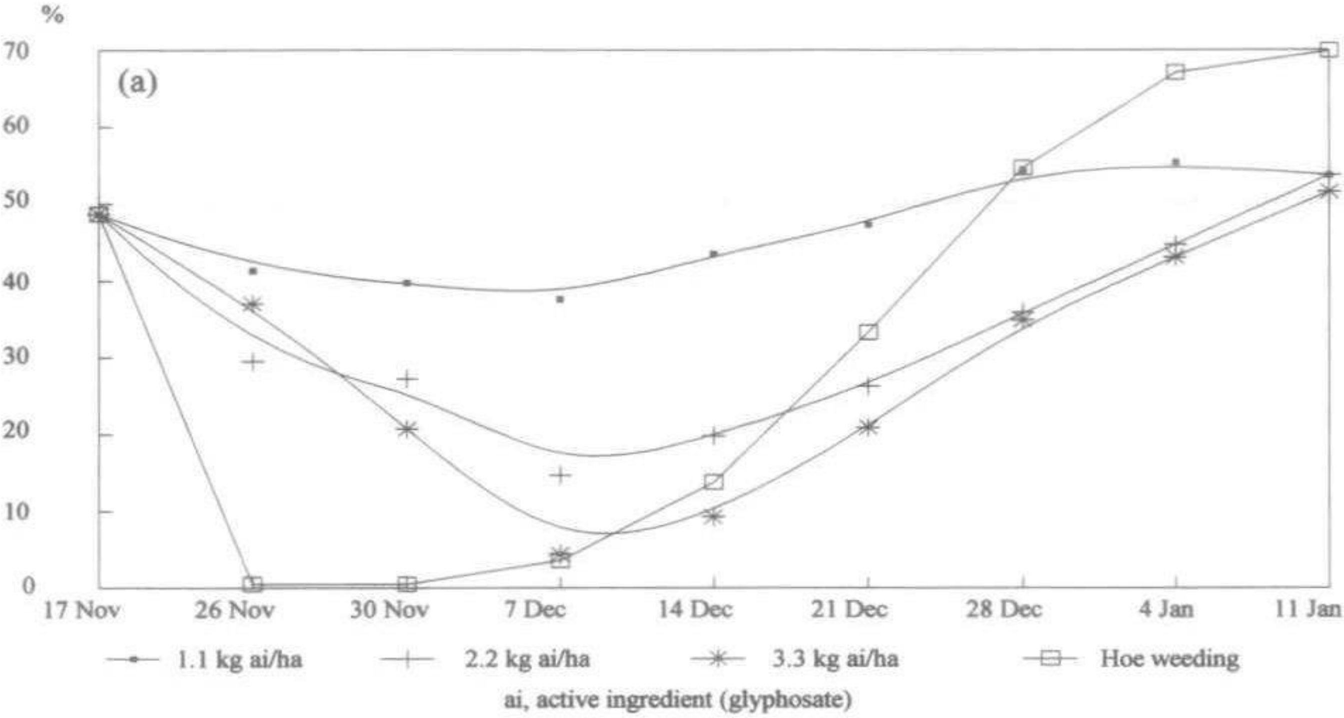
Fraction Probabilities			
Source	**Hoe weeding runs**		**End of season**
	13.12.93	11.1.94	
Block	0.113	0.002	0.002
Tillage	0.013	0.000	0.000
Weeding	0.000	0.001	0.003

The analysis of variance on the effect of weeding treatment on mean weed biomass production confirmed once more that traditional hoe weeding is ineffective for perennial weed control. While hoe weeding displayed the lowest weed biomass at first hoe weeding during the growing season (13 December 1993) it subsequently experienced the common early flush of annual weeds (Figures 3a-3c; Table 6). At the end of the season, the hoe-weeded check plots yielded poorly (Table 7). Equally poor was the performance of the lowest dosage of glyphosate (1.1 kg ai ha^{-1}). The two higher dosage rates (2.2 and 3.3 kg ai ha^{-1} respectively) performed significantly better, both with regards to weed suppression (Table 6) as well as maize grain and stover production (Table 7). From this it may be concluded that glyphosate dry formulation applied at 2.2 kg ai ha^{-1} is an effective means to control prolific Mexican clover and Couch grass infestations and thus that no higher application rates are required. However, given a current price (first quarter 1994) for one sachet of US$ 1,85 (equivalent to US$ 14 L^{-1}), even an application rate of 2.2 kg ai ha^{-1} (equivalent to 6 L ha^{-1} of the registered liquid formulation) will not be affordable for the large majority of Zimbabwe's smallholder farmers. Instead of spending approximately 85 US$ ha^{-1} on herbicides, the wealthier farmers will rather hire casual labourers at a current cost of approximately 20-30 US$ ha^{-1}. In addition, they would not need to buy a knapsack sprayer which costs approximately US$ 70 at current prices. Consequently, prices for Roundup Dry need to come down considerably in order to make this product competitive. In this context it should also be remembered, that reliance on one herbicide may lead to a build-up of resistant weed species (BORLAND, 1980; SOUTH, 1992), a scenario which holds some risk with regards to the control of Mexican clover by glyphosate (ARNOLD and ALDRICH, 1979). Again, farmers expressed interest in testing Roundup Dry on their fields and thus farmer-managed on-farm experimentation will commence during the forthcoming 1994-95 growing season.

Table 4: Effect of tillage treatment on mean weed biomass (kg ha^{-1}) at three dates during the 1993-94 growing season at Domboshawa, Zimbabwe[6].

Tillage treatments	**Hoe weeding runs** Kg. ha^{-1} 13.12.93	11.1.94	**End of season** Kg. ha^{-1}
Tied ridging	940a	1643a	581a
Conv. tillage	1498b	3132b	1222b
Clean ripping	1455b	4177c	2467c
SE	199	535	337

[6] Means followed by the same letter are not significantly different at $P < 0.05$. SE, standard error.



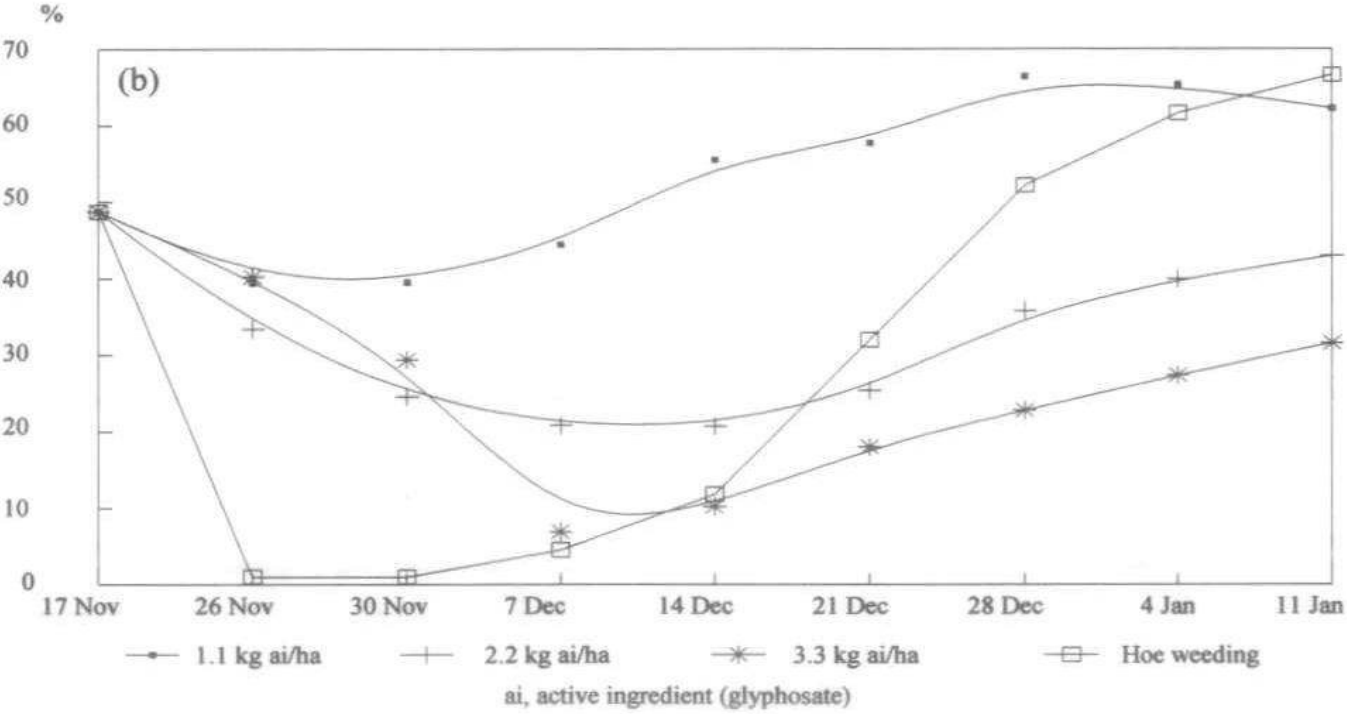


Figure 3: Weed ground cover development for four weeding treatments and three tillage treatments, (a) clean ripping, (b) conventional tillage, and (c) tied ridging during the early part of the 1993-94 season at Domboshawa, Zimbabwe.

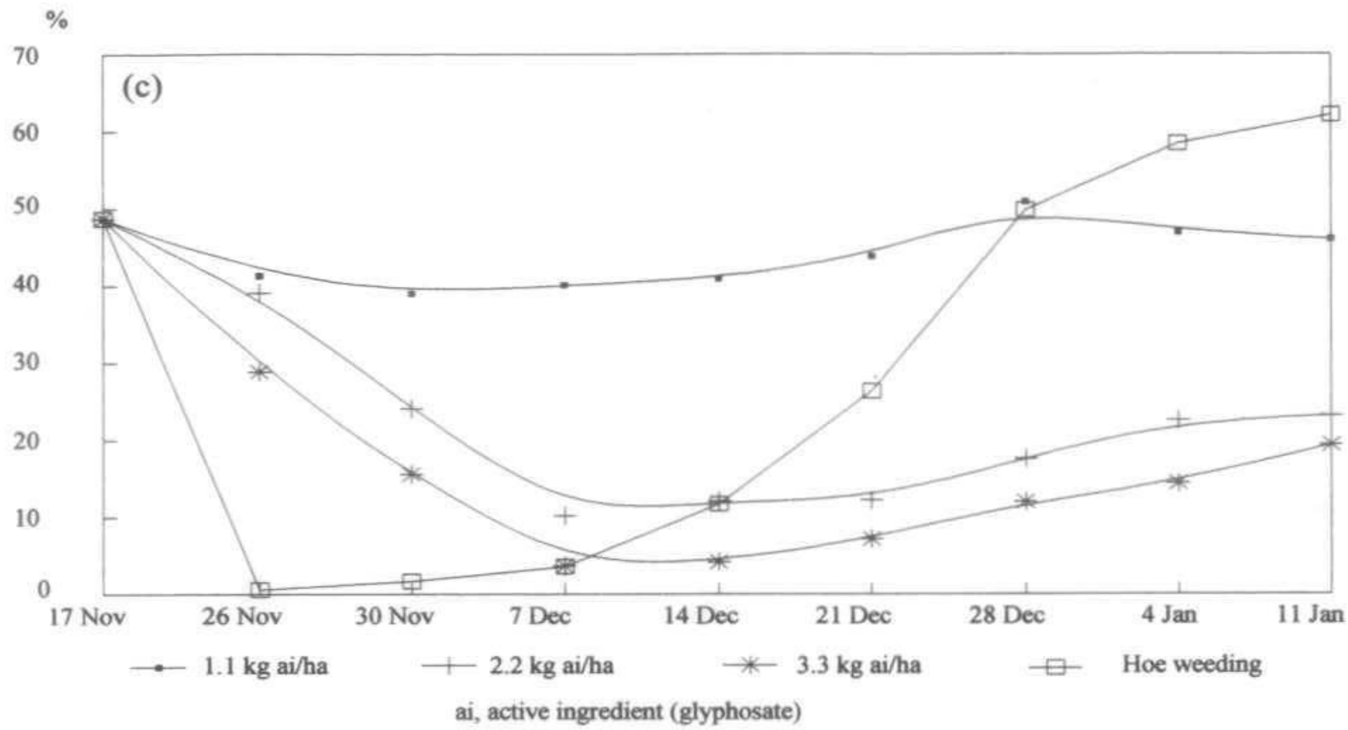


Figure 3: Weed ground cover development for four weeding treatments and three tillage treatments, (a) clean ripping, (b) conventional tillage, and (c) tied ridging during the early part of the 1993-94 season at Domboshawa, Zimbabwe.

Table 5: Effect of tillage treatment on maize grain and stover yields (kg ha^{-1}) during the 1993-94 growing season at Domboshawa, Zimbabwe.[7]

Tillage treatments	**Grain yield** Kg. ha^{-1}	**Stover yield** Kg. ha^{-1}
Tied ridging	4230a	4374a
Conv. tillage	2735b	2936b
Clean ripping	3010b	3105b
SE	296	340

[7] Means followed by the same letter are not significantly different at $P < 0.05$. SE, standard error.

Table 6: Effect of weeding treatment on mean weed biomass (kg ha^{-1}) at three dates during the 1993-94 growing season at Domboshawa, Zimbabwe.[7]

Glyphosate application rates[8]	Hoe weeding runs 13.12.93	11.1.94	End of season
1.1 kg ai ha^{-1}	2796c	3514b	2184b
2.2 kg ai ha^{-1}	1252b	2333a	847a
3.3 kg ai ha^{-1}	721a	1823a	941a
Hoe weeding only	422a	4266b	1721b
SE	230	618	389

Table 7: Effect of weeding treatment on maize grain and stover yields (kg ha^{-1}) during the 1993-94 growing season at Domboshawa, Zimbabwe.[7]

Glyphosate application rates[8]	Grain yield	Stover yield
1.1 kg ai ha^{-1}	2651a	2986a
2.2 kg ai ha^{-1}	3803b	3911b
3.3 kg ai ha^{-1}	3777b	4087b
Hoe weeding only	3070a	2903a
SE	342	393

3.4 Mixed cropping systems

One traditional, effective alternative to herbicides is mixed cropping systems (GIPS, 1987; AKOBUNDU, 1993). Research in Nigeria also indicates that mixed cropping systems are well suited for using low dosage rates of herbicides (GWORGWOR and LAGOKE, 1992). The studies at Domboshawa on strip cropping show that maize interplanted with cow peas and/or pumpkins needs to be weeded mechanically only once within 20 DAP. The dense ground cover provided by these cover crops thereafter suppressed weeds effectively season-long in most years and also increased total productivity. Since, in the tested system, maize is not only interplanted with other crops but also rotated annually in spatially alternating strips, it is to be expected that the weed seed reservoir will decrease considerably in future. Soils under maize-soya bean rotations have been found to harbour at least 50% less buried weed seeds than soil subjected to continuous maize production (FORCELLA and LINDSTROM, 1988). Since the project's on-farm trial programme has shown that mixed cropping, involving mainly beans and pumpkins, is already being widely practised by smallholder farmers, improved cropping systems such as strip cropping seem to be the

[8] ai = active ingredient

most readily acceptable option for improved weed management. However, because the agricultural extension service is still favouring clean monocultures, a major task will be to convince and train extension personnel. Specific efforts have been established as part of the project's participatory on-farm trial programme (HAGMANN, 1993).

4 Conclusions

In order to be attractive to farmers, conservation tillage systems need to be as effective and efficient in weed control as ploughing. The prevention of weed seed production is particularly crucial, as highlighted by the rapid build-up of Mexican clover. Since hoe weeding proved ineffective and inefficient in controlling Mexican clover (and Couch grass), available mechanical, biological and chemical technologies need to be combined in order to achieve satisfactory weed control. Based on the results of this study, integrating low rates of glyphosate and/or cover crops with one or two cultivations are technically sound weed management options for smallholder maize production systems. They are field-tested and ready to be adapted by farmers to suit their specific needs and resources.

5 Summary

This study in Zimbabwe revealed that conservation tillage systems subjected to continuous maize production to lead to unacceptably high levels of perennial weed infestation within six years. Traditional hoe weeding proved unable to control the rapid build-up of perennial weeds, most likely because seeds were not buried deep enough and the observed deep tap roots and the rhizomes could not sufficiently be lifted out of the soil. Similarly, blade weeders designed to cut through weed roots at shallow depth did not cope adequately with prolific perennials. In fact, perennials may even have reproduced from cuttings. However, the tested blade weeders reduced weeding time considerably compared to hoe weeding and are thus well suited for controlling newly emerged annuals. Preseeding herbicide application using glyphosate at a rate of 2.2 kg ai ha^{-1} or intercropping maize with cow peas and pumkins showed greatest potential as alternative weed management options. They both suppressed perennial weeds effectively. Intercropping also had the additional benefit of increasing overall crop production thus minimizing the always present risk of total crop failure in continuous smallholder maize production. Since mixed cropping also is a traditional practice, it appears to be the most promising and appropriate weed management option for further promotion and extension in smallholder conservation farming.

Die Notwendigkeit integrierter Unkrautbekämpfung bei konservierender Bodenbearbeitung in kleinbäuerlichen Betrieben

Zusammenfassung

Diese Studie im Norden von Zimbabwe ergab, daß sich perenne Unkrautarten im Maismonokulturanbau bei konservierender Bodenbearbeitung innerhalb von 6 Jahren über Gebühr vermehren. Die traditionelle Unkrautbekämpfung mit der kurzstieligen Handhacke erwies sich im Falle perenner Samen- und Wurzelunkräuter als ungeeignet, wahrscheinlich weil Unkrautsamen nicht tief verschüttet und tiefreichendes Wurzelwerk und weitläufige Rhizome nicht ausreichend herausgerissen wurden. Hacken mit Messern erwiesen sich in der Bekämpfung der in großen Dichten auftretenden Problemunkräuter ebenfalls als ungeeignet. Darüberhinaus dürften die infolge der schneidenden Arbeitsweise geschaffenen Schnittstücke den Besatz perenner Wurzelunkräuter eher noch erhöht haben. Die getesteten Messerhacken verringerten jedoch den Arbeitskraftstundenbedarf im Vergleich zum Handhackeneinsatz beträchtlich und erschienen somit gut geeignet in der frühen Bekämpfung annueller Unkrautarten. Der Einsatz von Roundup im Vorsaatverfahren oder Maismischkulturen zeigten das größte Potential als Alternativen zur traditionellen Unkrautbekämpfung mit der Handhacke. Beide Maßnahmen verringerten den Besatz perenner Unkrautarten wirkungsvoll. Mischkulturen boten darüberhinaus den zusätzlichen Vorteil erhöhter Gesamtproduktion, wodurch die im Maismonokulturanbau ständig gegebene Gefahr einer Mißernte gering gehalten wird. Da Mischkulturen auch ein traditionelles Anbauverfahren darstellen, erscheinen sie die aussichtsreichste und angepaßteste Form der Unkrautbekämpfung bei konservierender Bodenbearbeitung in klein-bäuerlichen Betriebssystemen zu sein.

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APPENDIX

Ox-drawn tine cultivator and donkey-pulled blade cultivator.