Crop and weed responses to residue retention and method of weeding in first two years of a hoe-based minimum tillage system in semi-arid Zimbabwe

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Abstract

Many argue that residue retention and effective weed management are the two components limiting the uptake of conservation farming by smallholder farmers in southern Africa. An experiment was carried out at Matopos Research Station, Bulawayo, Zimbabwe to determine the effects of crop residue retention and weeding method on weed biomass, and maize (*Zea mays*) and sorghum (*Sorghum bicolor*) yields. The experiment was conducted in the 2004/05 and 2005/06 cropping seasons on clay loam and sandy soils. The study was set up as a split-plot design with residue retention (0, 25, 50, 75 and 100% of previous season's stover) as main-plot factor and weeding method (hoe-weeding and glyphosate applied with the Zamwipe®) as a sub-plot factor. Each treatment was replicated three times on each soil type. Hoe-made planting basins for maize (cultivar SC 403) and planting furrows for sorghum (variety Macia) were prepared after which residue was applied in the dry season. The crops were planted after the first effective rains of the season. Weed biomass and crop yield were measured under each treatment. In both seasons crop residue retention did not have a significant effect on crop yield irrespective of soil type. In both maize and sorghum in 2005/06 season, retaining the available crop residue (2.5 t ha^{-1} and below) did not result in significant weed suppression. The Zamwipe® proved difficult to use in both years resulting in significantly lower crop yield in the second season due to poorer weed control than observed in hoe-weeding. Furthermore, results from sorghum grown on the sandy soil suggest that the crop residue that was spread uniformly over the plots may have interfered with the Zamwipe®. Thus, the weed wipe requires further mechanical improvements. Since the effects of residue retention are viewed as cumulative, more detailed long-term studies are needed to understand the implications of residue retention in mixed crop-livestock systems.

Introduction

Conservation agriculture (CA) is being promoted to smallholder farmers in southern Africa to improve crop yields through improved resource management (Haggblade and Tembo 2003a). Conservation agriculture comprises minimum tillage, provision of semi-permanent soil cover and crop rotation, practiced in tandem with good crop management (http://www.fao.org/ag/ca/1a.html; accessed on 4 July 2007). However, since most smallholder farmers in southern Africa lack access to draft power (Twomlow et al. 2006), tillage in CA is conducted using small farm implements rather than large mechanized implements. In this region, hand hoes are used to dig permanent planting basins to a depth of 0.15 m every dry season with the area in between basins left undisturbed. This hoe-based minimum tillage practice with provision of soil cover and crop rotation is termed conservation farming in both Zimbabwe and Zambia. However, most smallholder farmers in these countries are mainly practicing minimum tillage without residue retention and crop rotation (Haggblade and Tembo 2003b, Hove and Twomlow 2008).

Smallholder farmers using the CA minimum tillage practice of planting basins have reported an increase in crop yield that they attribute to more timely planting (Mazvimavi et al. 2007, Twomlow et al. 2009). However, without plowing as an early method of weed control, weeding can become a problem. Minimum tillage practices had higher weed infestations than plowed fields in Zambia (Muliokela et al. 2001) and were associated with perennial weed population increases in Zimbabwe (Vogel 1994). Such adverse changes in weed composition largely contribute to increased labor requirements for hoe-weeding minimum tillage fields (Vogel 1994, Haggblade and Tembo 2003a). With critical labor shortages (Steiner and Twomlow 2003) and weeds being a major constraint to crop production (Twomlow et al. 2006), there is an urgent need to develop effective weed management strategies if minimum tillage systems are to be widely promoted in southern Africa's smallholder sector.

Globally there is mounting evidence that retention of crop residues from one season to the next suppresses the germination and development of weeds in minimum tillage systems, thus enhancing system productivity. In Zambia, Gill et al. (1992) identified residue mulching as a practical method for early season weed control in minimum tillage systems for smallholder farmers. This was because applying grass mulch at 5 t ha^{-1} significantly suppressed weed growth in the first 42 days of maize (*Zea mays*) grown under minimum tillage. Similar observations were made by Vogel (1994) in Zimbabwe where retention of the previous season's maize residues significantly suppressed by more than 30% the total dry weed biomass in ripped plots compared to the un-mulched treatment. In USA, work by Buhler et al. (1996) showed that retaining above 5 t ha^{-1} of maize residue often reduced the density of some annual weeds in untilled soils.

However, the effect of surface mulching on weeds is not consistent. In another experiment done by Gill et al. (1992) in Zambia on the same site and year as the study mentioned above, significant weed suppression in maize grown under minimum tillage was observed only at grass mulch rates of 15 and 20 t ha^{-1}. Furthermore in USA, Buhler et al. (1996) observed that in a drought year, maize residue mulching resulted in increased weed growth. Thus, the changes in the soil microenvironment that result from surface mulching (Erenstein 2003) can result in either suppression in germination of annual weeds (Bilalis et al. 2003) or increased weed growth of some weed species (Chauhan et al. 2006). In the cases where significant weed suppression occurred thick layers of organic residues were applied (Teasdale and Mohler 2000). This translates into high mulch rates, which limits the applicability of mulching for smallholder farmers (Erenstein 2002), especially those in dry areas. Surface mulching of soil using crop residues is limited by the multiple use of harvested residues by farmers especially use of crop residues as livestock fodder (Lal 2007, Mazvimavi et al. 2007). Thus, other weed control methods may be needed to reduce crop yield losses.

The majority of African smallholder farmers use hoe-weeding as the main method to control weeds (Makanganise et al. 2001). This weeding strategy is, however, time consuming and labor intensive (Chivinge 1990) with up to 300 person-hours ha^{-1} required to weed maize in moldboard plowed fields where perennial weeds such as *Cynodon dactylon* are a problem (Vogel 1994). In addition, hoe-weeding is ineffective against perennial weeds that require deep cultivation for control. According to Haggblade and Tembo (2003b), the labor requirement for hoe-weeding a whole field of planting basins is about three times that of plowed fields. Since labor bottlenecks especially early in the season often result in untimely weeding in plowed field (Makanganise et al. 2001) leading to more than 30% loss of potential yield of cereal crops (Riches et al. 1997), the situation can only be worse in planting basins. Hence, minimum tillage practices that rely purely on hoe-weeding may not be an attractive option for smallholder farmers (Vogel 1994).

The use of herbicides can facilitate the uptake of minimum tillage as it eliminates early crop-weed competition and reduces the time farmers spend on weeding (Gatsi et al. 2001, Locke et al. 2002). Work done on Zimbabwean smallholder farms showed that applying atrazine significantly reduced labor required for weeding (Gatsi et al. 2001) and increased maize yields (Chikura 2000) in reduced tillage systems. Application of herbicides in ripped fields gave the highest net returns to labor compared to hoe-weeding (Chikura 2000). However, the use of herbicides in smallholder agriculture is low mainly because of the high cost of purchasing herbicides and sprayers (Gatsi et al. 2001). Thus, the availability of low-cost herbicide applicators can be one way of reducing the expense of chemical weed control for smallholder farmers (Steiner and Twomlow 2003). One such applicator is the Zamwipe®, a type of weed wipe developed in Zambia for use by conservation farmers (Fig. 1). The Zamwipe® is simple, cheap, light and easy to

Figure 1. The Zamwipe® – a glyphosate applicator used to control weeds by conservation farmers in Zambia. Insert: Modified wiping head used in this study.

maintain compared to the knapsack sprayer (CFU 1997). It reduces weeding labor from 70 to 15 person-days ha^{-1} and this is more economical than hand weeding; it also reduces herbicide wastage (Haggblade and Tembo 2003b).

The purpose of this study is to determine the effect of retaining different proportions of cereal residues in combination with either hoe-weeding or glyphosate applied with Zamwipe® on weed growth and maize and sorghum (*Sorghum bicolor*) yields on clay loam and sandy soils.

Materials and method

Study sites. The study was conducted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Matopos Research Station farm (28°30' E, 20°23' S). The station is located about 30 km south of the city of Bulawayo and is considered to be representative of climatic conditions found in southwest Zimbabwe (Pulina et al. 1999) and much of Botswana, southern Mozambique and Zambia (Twomlow et al. 2006). The research station is underlain by different parent material giving rise to two dominant soil types. The northern part has micaceous schists whereas gneissis granites underlie areas to the south. To capture this difference in soil types, trials were carried out at West Acre (28°30.92' E, 20°23.32' S; 1344 m above sea level) and Lucydale (28°24.46' E, 20°25.64' S; 1378 m above sea level) sites. West Acre soils are clay loams classified as Chromic-Leptic Cambisol with 41% clay in the topsoil whereas Lucydale soils are sandy Eutric Arenosols with 4% clay content in the topsoil (Moyo 2001). The physical properties of soils on the two study sites are summarized in Table 1. The majority of soils in Zimbabwe's smallholder sector are similar to soils at Lucydale.

Matopos has a seasonal climate with a hot dry season, main wet season and a cool winter season. The dry season occurs from September to mid-November and is characterized by low humidity and high temperatures that peak in October at 29°C (Dye and Walker 1987). The rainy season begins around mid-November with rainfall often occurring as convectional storms until March. There is large annual variability in total rainfall with precipitation ranging from 250 to 1400 mm. The mean long-term annual rainfall of the station is 590 mm (Ncube 2007). Winters are dry and cool with mean minimum temperature of 10.7°C. The majority of smallholder farmers in southern Zimbabwe practice rainfed agriculture. However, crop production in southwestern Zimbabwe is risky due to low and erratic rainfall. Farmers grow drought-tolerant crops such as sorghum in addition to the staple maize crop to ensure food security (Rohrbach 2001).

Experimental layout. The experiment was set up as a split-plot design with five levels of residue retention (0, 25, 50, 75 and 100% of stover yield) as the main factor. The sub-plot factor was weeding method using either hand hoes or application of glyphosate with Zamwipe®. Each treatment was replicated three times on both soils. Maize and sorghum were grown over the course of the two seasons on each soil type.

In the maize study, hand hoes were used to remove weeds and prepare land in September of each season. Planting basins of 15 cm × 15 cm × 15 cm dimension were dug at an interrow spacing of 90 cm and 60 cm between basins within row, as per guidelines of the Zimbabwean Conservation Agriculture Task Force (Twomlow et al. 2008). Maize residue was applied uniformly over the main plots of 10 m × 10 m at the end of September. In September 2004, maize stover was imported from other

Table 1. Physical and chemical characteristics of West Acre and Lucydale soils[1].

	West Acre				Lucydale			
Soil property	Chromic-Leptic Cambisol				Eutric Arenosol			
Depth (cm)	0–6	6–16	16–40	40–60	0–12	12–24	24–35	35–57
Clay (%)	41	38	47	52	4	5	6	10
Silt (%)	20	23	17	17	4	5	4	3
Sand (%)	38	39	36	31	91	91	99	87
Gravel (%)	–	–	–	–	5	7	8	17
pH ($CaCl_2$)	7.5	7.6	7.7	7.8	5.0	4.9	4.8	5.5
OC (%)	0.46	0.80	0.37	0.48	0.00	0.00	0.04	0.00
Ca ($Cmol_c\ kg^{-1}$)	40.2	40.9	32.3	33.4	1.2	0.80	0.70	3.1
Mg ($Cmol_c\ kg^{-1}$)	14.8	15.4	16.6	19.7	0.40	1.00	0.70	2.2
K ($Cmol_c\ kg^{-1}$)	1.98	1.77	1.64	1.67	0.02	0.03	0.03	0.04

1. Source: Moyo (2001).

fields and application rates were determined using the average maize stover yields for 2003/04 cropping season obtained from the Crop Production Unit, Matopos Research Station for each of the two soil types. In the following season, the average maize stover yield for 2004/05 season for each soil type was used (Table 2). Cattle kraal manure was applied as a basal fertility amendment in October at a rate of a handful per basin to give an application rate of 2 t ha^{-1}. Planting was done in December after receiving above 30 mm rainfall on sandy soil and 50 mm on clay loam. Three maize pips of an early-maturing maize cultivar (SC 403) were planted per basin. At 4 weeks after planting (WAP) the crop was thinned to two plants per basin to give a target population of 37,037 plants ha^{-1}.

Weeding was carried out three times at 4, 7 and 11 WAP so as to prevent weeds from seeding and adding to weed soil seed bank as recommended under CA. Half of the main plot was hoe-weeded while the other half received glyphosate applied using a Zamwipe® applicator. Glyphosate (ai isopropylamine salt 41%) was applied at 4 L ha^{-1} in 100 L of water. The herbicide mix was poured into the reservoir on top of Zamwipe® from which it was fed by gravity through a tube inside the handle to the wiping head. Once the head was observed to be soaked with herbicide, weeds within a crop row were wiped using a backward and forward motion making sure that weeds were coated by the herbicide mix. To avoid crop damage, weeds close to the crop were hand weeded. At 5 WAP ammonium nitrate was applied at 28 kg nitrogen (N) ha^{-1} [one level Crown agent bottle cap of ammonium nitrate (34.5% N) spot placed between two plants]. The rates of fertilizers used in the trials are based on ICRISAT's work on identifying fertilizer rates that will give the best economic rates of return for resource-poor farmers in semi-arid areas of southern Africa (Ncube et al. 2007).

For sorghum, a planting method similar to the traditional method carried out by smallholder farmers of dribbling the small grain seed was used. Shallow furrows spaced 75 cm apart were made in September using hand hoes. Sorghum residue was applied as in the first experiment using average yields from the previous season (Table 2). Manure was applied along furrows at an application rate of 2 t ha^{-1}. The sorghum variety Macia was planted in December. At 4 WAP sorghum plants were thinned to leave a spacing of 20 cm between plants to give a target population of 66,666 plants ha^{-1}. At 5 WAP, 28 kg N ha^{-1} was spot applied to sorghum crops. All other management practices were the same as those for maize.

Table 2. Agronomic and trial management information.

Agronomic factor	Maize	Sorghum
Cultivar	SC 403	Macia
Spacing (m)	0.9 × 0.6	0.75 × 0.20
Seed rate (kg ha^{-1})	30	7
Average stover yield (t ha^{-1})		
West Acre (2003/04)	4.5	3.0
West Acre (2004/05)	2.3	1.8
Lucydale (2003/04)	3.0	2.0
Lucydale (2004/05)	1.5	1.0

Data collection. Weed biomass was measured and recorded before weeding at 7 WAP and at 11 WAP. A 0.3 m × 0.3 m quadrat centered on the crop row and adjacent interrow area was thrown at two random positions in each sub-plot. The weeds within each quadrat were cut above ground level and put in an oven at 60°C for 48 hours to measure dry weed mass. At harvest, grain and stover yields were determined per net sub-plot area from the central three rows. Grain yield was adjusted to 12.5% moisture content.

Statistical analysis. Grain yield, stover yield and dry weed mass data was analyzed using GenStat Release 10.1 (Lawes Agricultural Trust, Rothamsted Experimental Station, UK). Analysis of variance for a split-plot design was used to determine the effect of mulching rate and weeding practice on crop yield and weed biomass. The treatment and interaction SED were used to separate treatment means at the 5% level of significance. The relationship between residue retention levels and weed biomass and yield was determined through regression analysis.

Results and discussion

Rainfall

The cumulative rainfall observed on the clay loam and sandy soils over the two seasons of the study is shown in Figure 2. Total rainfall in the 2004/05 cropping season was below the yearly average for Matopos. In contrast, the following season received above average rainfall that was double the amount received in 2004/05. The two seasons also differed in terms of rainfall distribution with the 2005/06 cropping season having a better rainfall distribution than the preceding season (Fig. 2). In both seasons, about 10% more rainfall was received on clay loam than on sandy soil.

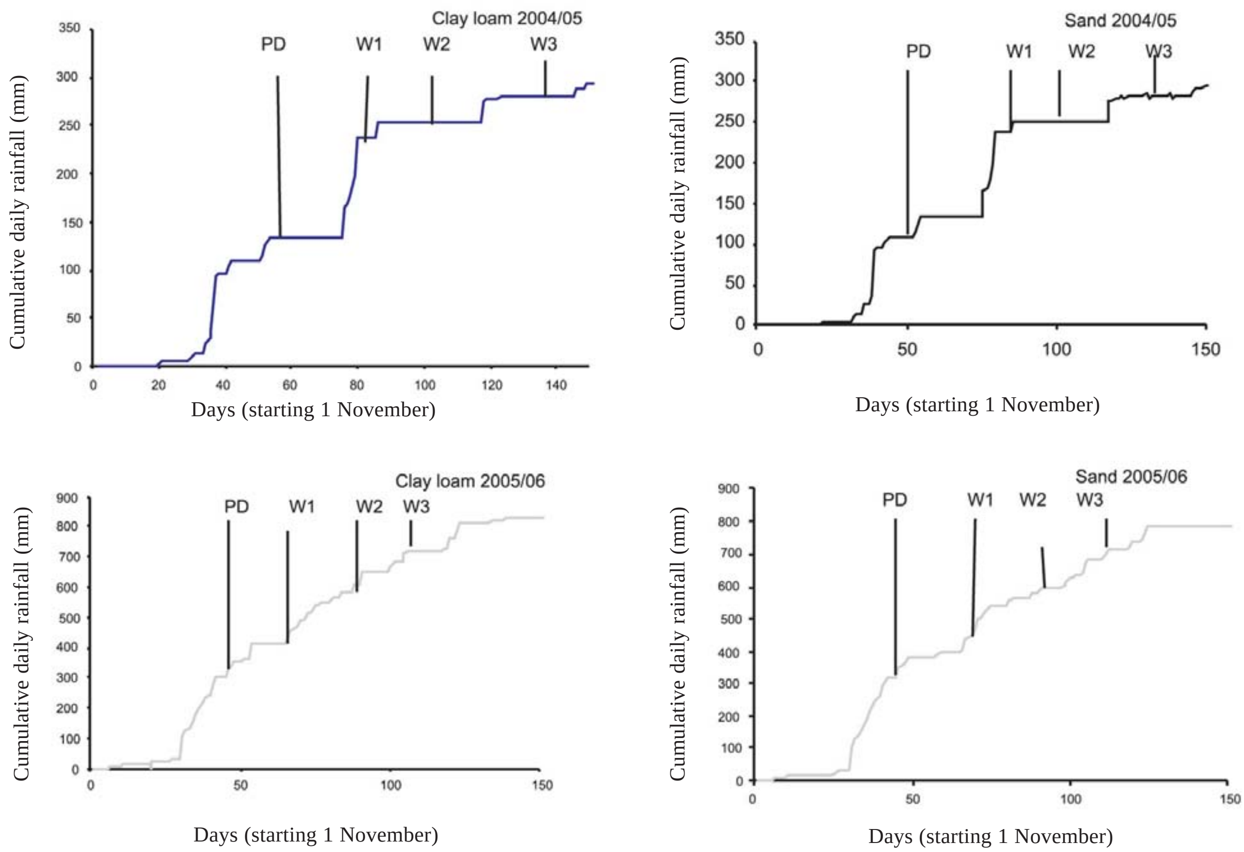

Figure 2. Rainfall received between 1 November and 31 March during 2004/05 and 2005/06 cropping seasons on clay loam and sandy soil and timing of important operations. (Note: PD = planting date; W1 = first weeding; W2 = second weeding; and W3 = third weeding.)

Crop response to cereal residue retention

Cereal yield. In the 2004/05 season, there was no significant yield benefit to retaining available maize and sorghum residues on both the clay loam and sandy soils (Table 3). Similar trends were obtained for stover yield. Since this season had below average rainfall (Fig. 2) residue retention was expected to improve crop yield through improved soil moisture availability. Improvements in soil moisture with increasing maize mulch rate were observed by Mupangwa et al. (2007) in a complementary study on the sandy soil at Matopos Research Station in the 2004/05 season. However, this increase in soil water content did not translate into significant maize yield increases even at mulch rates of 10 t ha^{-1}. It is probable that soil fertility became a limiting factor to maize growth.

Probert (2007) used a modeling approach to determine the relationship between residue retention and crop productivity under zero-tillage management in the semi-arid tropics. The scenario analysis conducted on case studies in southern Africa and Australia using the Agricultural Production Systems Simulator (APSIM) showed that retention of maize and wheat (*Triticum aestivum*) residues had modest effects on average long-term crop production. Trends for Makoholi, a research station in central southern Zimbabwe with sandy soil with soil organic carbon (SOC) of 0.5% showed that retention of 2.5 t ha^{-1} of residue was sufficient to maintain the initial SOC. However, simulation when SOC was at 0.75%

showed that the amount of residue needed to maintain SOC increased to 4 t ha^{-1}. This level was the 100% residue retention rate at this site. However, applying the entire residue at Makoholi when combined with sub-optimal N fertilization practices failed to maintain initial SOC levels. Application of 15 kg N ha^{-1} was associated with a slight decline in SOC with time and declined where no N was applied. Based on Probert's findings (2007), the amount of residue and N fertilizer applied is unlikely to have increased the low SOC of sites. This explains the lack of yield response to mulching in the 2004/05 season where moisture increases did not translate into grain benefits. There is, thus, a need to combine mulching with appropriate nutrient management practices so as to obtain the greatest yield.

There was no significant (P >0.05) short-term yield benefit to residue retention in maize and sorghum crops grown on the two soil types in 2005/06 season. This season was characterized by above average rainfall such that soil moisture was not limiting. Since the previous season was dry, stover yields were low such that residue available for retention was below 5 t ha^{-1}. However, due to the good rains received crop yields were higher than for previous seasons. The yields on the clay loam were quite high especially in hoe-weeded plots. The clay loam at ICRISAT has been used for crop breeding trials with high input management; so crops probably benefited from residual fertilizers. The clay loam is inherently more fertile than the sandy soil (Table 1) and with more rainfall (Fig. 2) and this led to high crop yields.

Table 3. The effect of residue retention on maize and sorghum grain yield on two soil types at Matopos Research Station in 2004/05 cropping season[1].

	Grain yield (t ha^{-1})	
Residue rate (%)	Clay loam	Sand
Maize		
0	2.0	0.3
25	1.7	0.3
50	1.9	0.3
75	1.7	0.2
100	2.0	0.3
SED	0.41	0.19
Sorghum		
0	0.8	0
25	0.7	0
50	0.7	0
75	0.9	0
100	0.7	0
SED	0.17	

1. All sub-plots hoe-weeded from second weeding.

Weeds. The original Zamwipe® used in this study had a wiping pad that was unsecured within the wiping head so as to facilitate cleaning of pad after each weeding operation (CFU 1997). However, the unsecured wiping pad fell out of wiping head during the weeding operation. At the first weeding in 2004/05, it was found out that the weeding operation was time consuming as the pad required cleaning after coming into contact with the soil. Although the weeds turned yellow they did not die (Fig. 3). With time these weeds grew such that by the time of the second weeding at 7 WAP there were very high weed infestations in plots where glyphosate was applied. Advice was then sought from the Zamwipe PVT (Ltd), the makers of Zamwipe®, on how to address this problem. It was decided to weed all plots at 7 WAP and not collect weed biomass in this season. The weed biomass presented here is for the 2005/06 cropping season when following advice from Zamwipe PVT (Ltd), the wiping pad was tied within the wiping head using a string (Fig. 1).

Neither retention of maize nor sorghum residue had a significant effect on weed biomass at 7 and 11 WAP in the 2005/06 cropping season on both the clay loam and sandy soil (Tables 4 and 5). The lack of a statistically significant weed response to residue retention was probably due to the amount of maize and sorghum residues that was available for application in the 2005/06 cropping season. Crop residue yield from the previous season was below 2.5 t ha^{-1} for both maize and sorghum with a greater yield obtained from the clay loam than sandy soil plots (Table 2). It is likely that the low amounts applied had mostly decomposed by 7 WAP when weed biomass was measured and amounts left on soil surface

Figure 3. Variation in weed mortality where glyphosate was applied using the Zamwipe® in February 2006 on sorghum grown on clay loam soil at Matopos Research Station.

were insufficient to change the soil microenvironment in a way that significantly affected weed growth.

A review of studies on the effect of surface mulching on weeds by Chauhan et al. (2006) showed that significant weed suppression occurred when organic mulches were applied at rates that were higher than the average stover yields of most fields. Teasdale and Mohler (2000) observed that greater than 75% inhibition of weed emergence was consistently achieved when residue biomass exceeded 8 t ha^{-1}, resulting in a mulch thickness of more than 10 cm. This agrees with observations of Mupangwa et al. (2007) on maize grown in planting basins at Lucydale (sand) in 2004/05 where mulching with maize residue significantly (P = 0.01) suppressed weed density at rates of 8 and 10 t ha^{-1} but not at lower rates. Despite these reports smallholder farmers are encouraged to retain whatever crop residue is available on their CA fields by organizations promoting CA. However, based on results from this study and others, retaining all the available crop residues on smallholder farmers' fields is unlikely to positively contribute to weed management at current stover yield levels.

Weeding method effects

Crop yield. Crop yield was significantly (P <0.05) affected by weeding method in the 2005/06 cropping season (Tables 4 and 5). Across all residue retention levels weeding using the Zamwipe® resulted in more than 50% reduction in yield of maize and sorghum on both soils. The same trend was observed on stover yield. Glyphosate application using Zamwipe® resulted in greater weed growth than in hoe-weeded plots as shown by weed biomass measured at 7 and 11 WAP (Tables 6 and 7). The increased weed competition for nutrients and water in plots that received chemical weed control resulted in yield reduction. According to Riches et al. (1997), competition between crops and weeds for resources commonly results in more than 30% yield decline in smallholder agriculture.

Weed biomass. Despite the modification to wiping pad, use of the Zamwipe® resulted in a significant increase in weed biomass in maize at 7 WAP (P = 0.019) and 11 WAP (P = 0.002) on the sandy soil with a similarly significant trend observed in sorghum grown at the same

Table 4. Maize response to residue retention and weeding method in 2005/06 cropping season on two soils at Matopos Research Station.

	Maize grain yield (t ha^{-1})		
Residue (%)	Hoe-weeding	Zamwipe®	Mean
Clay loam			
0	8.1	1.8	4.9
25	4.7	2.7	3.7
50	6.4	1.9	4.1
75	6.1	1.8	3.9
100	3.8	2.3	3.0
Mean	5.8	2.1	
Residue SED	0.71		
Weeding SED	0.69		
Interaction SED	1.30		
Sand			
0	1.5	0.2	0.9
25	2.3	0.0	1.2
50	0.9	1.0	0.9
75	2.0	0.9	1.4
100	1.9	0.4	1.4
Mean	1.7	0.5	
Residue SED	0.31		
Weeding SED	0.42		
Interaction SED	0.73		

Table 5. Response of sorghum to residue retention and weeding method in 2005/06 cropping season at Matopos Research Station.

	Sorghum grain yield (t ha^{-1})		
Residue (%)	Hoe-weeding	Zamwipe®	Mean
Clay loam			
0	3.3	0.6	1.9
25	2.0	1.6	1.8
50	3.1	0.1	1.6
75	4.5	0.6	2.5
100	3.2	0.1	1.7
Mean	3.2	0.6	
Residue SED	0.48		
Weeding SED	0.49		
Interaction SED	0.91		
Sand			
0	0.6	0.0	0.3
25	0.3	0.2	0.3
50	0.4	0.0	0.2
75	0.5	0.0	0.3
100	0.6	0.0	0.3
Mean	0.5	0.0	
Residue SED	0.19		
Weeding SED	0.13		
Interaction SED	0.28		

Table 6. Weed biomass (g m^{-2}) response to retention of different rates of maize residue in a maize crop grown on two soil types at Matopos Research Station in 2005/06.

	Clay loam		Sand	
Residue retention (%)	7 WAP[1]	11 WAP	7 WAP	11 WAP
0	324	48	76	25
25	188	38	224	7
50	278	47	216	10
75	211	27	254	13
100	237	25	257	16
Mean	248	37	205	14
SED	66.2	22.2	117.7	8.2

1. WAP = Weeks after planting.

Table 7. Response of weed biomass (g m^{-2}) to retention of different rates of sorghum residue in a sorghum crop grown on two soils at Matopos Research Station in 2005/06.

	Clay loam		Sand	
Residue retention (%)	7 WAP[1]	11 WAP	7 WAP	11 WAP
0	180	42	150	4
25	112	61	216	5
50	212	40	191	15
75	101	54	194	13
100	127	48	164	15
Mean	196	49	224	10
SED	43.0	31.2	85.7	8.4

1. WAP = Weeks after planting.

site (Tables 8 and 9). On the clay loam there was no significant difference in weed biomass between the two weeding methods although a lower weed biomass was obtained from hoe-weeding than glyphosate-treated plots. The modification to the wiping head probably led to changes in glyphosate flow rate and reduced the area of wiping pad that was in contact with weeds. This is suggested by the variations in weed kill that were observed within and among plots where glyphosate was applied. In some plots there was complete desiccation of weeds but in others (Fig. 3) there was variation in herbicide efficacy with some weeds simply turning yellow.

Residue retention rate × weeding method interaction. There was a significant (P = 0.017) residue retention × weeding method interaction on weed biomass at 7 WAP on the sandy soil in 2005/06 (Fig. 4). The significantly higher weed biomass observed in Zamwipe® plots

Table 8. Weed biomass (g m^{-2}) in maize in response to weeding method on two soil types at Matopos Research Station during the 2005/06 cropping season.

	Clay loam		Sandy	
Weeding method	7 WAP[1]	11 WAP	7 WAP	11 WAP
Hoe-weeding	162	39.6	155	2.9
Zamwipe®	333	34.0	256	24.8
SED	78.3	10.3	36.4	5.2

1. WAP = Weeks after planting.

Table 9. Weed biomass (g m^{-2}) in sorghum in response to weeding method on two soil types at Matopos Research Station during the 2005/06 cropping season.

	Clay loam		Sandy	
Weeding method	7 WAP[1]	11 WAP	7 WAP	11 WAP
Hoe-weeding	162	43.8	136	7.3
Zamwipe®	131	54.2	230	13.3
SED	43.8	11.2	34.3	4.04

1. WAP = Weeks after planting.

occurred only where 50% or more sorghum residue was retained. When 0% and 25% sorghum residue was maintained, weed biomass did not statistically differ between hoe-weeding and Zamwipe®. This suggests that the presence of increasing sorghum stover at the soil surface may have reduced efficacy of the Zamwipe®.

Retention of crop residues has been reported to result in interception of about 15 to 80% of applied herbicide (Streit et al. 2003). In the case of post-emergence herbicides such as glyphosate, the effective herbicide contact with emerging seedlings is reduced (http://anrcatalog.ucdavis.edu; accessed on 8 January 2008). In this study, crop residues may have shielded some weeds from herbicide and/or adsorbed glyphosate resulting in weed escapes. The effect was not so pronounced in maize probably due to the application of maize residue that mainly comprised stalks. The sorghum residue applied in this study had greater leaf material than the maize residue and this may have led to a greater interception of herbicide or shielding of small leaves under residues. The interception of applied herbicide by crop residue has implications on weed management especially where high amounts of residues (as promoted in CA) are used in that herbicides may need to be applied when weeds are above residue layer. However, for weeds emerging with crops such delays in control can result in significant crop yield loss.

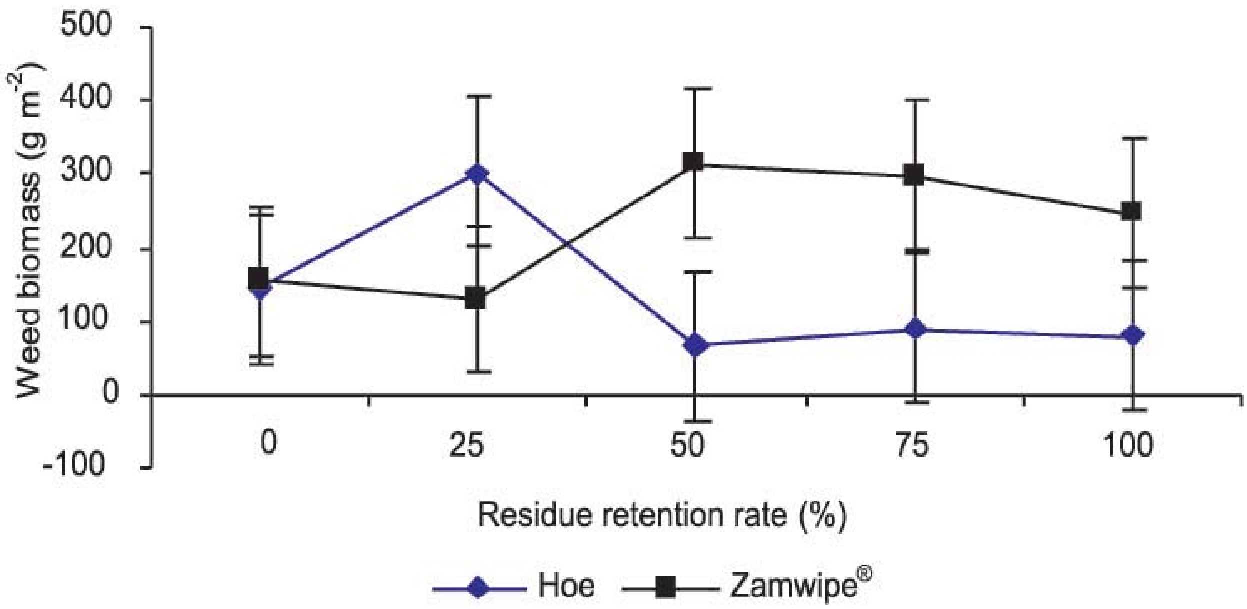

Figure 4. Weed biomass response to residue retention rates and weeding method in sorghum at 7 weeks after planting on sandy soil at Matopos Research Station in 2005/06 cropping season (Bars = SED).

Conclusion

Surface mulching using available maize and sorghum residues did not significantly increase maize and sorghum yields on the clay loam and sandy soils over two contrasting seasons. The results of this study suggest little or no short-term yield benefits from using available crop residue as surface mulch in semi-arid areas of southern Africa. Furthermore, the weeding burden of farmers in an above average rainfall situation is unlikely to be reduced by retaining the low amounts of available crop residues. Farmers may have to mainly depend on hoe-weeding for weed control as in this study using the Zamwipe® as a sole weed control method resulted in high weed competition and low crop yields. This was due to problems with the unsecured wiping pad that fell out during weeding. The significant interaction of residue retention and weeding method in sorghum grown on sandy soil suggested that the presence of sorghum residue reduced the weed wipe's efficacy. Based on the results from this study, effective weed control is likely to remain a major challenge in the early years of conservation farming. It is, thus, recommended that farmers put under planting basins an area that will be manageable using available family labor. More detailed studies on the effect of mulching on the soil moisture, temperature and decline in soil cover need to be done both on-station and on-farm. Further mechanical improvements are required for the Zamwipe® so that the promising technology can be used by smallholder farmers to effectively control weeds.

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