African Journal of Agricultural Research Vol. 7(36), pp. 5069-5082, 18 September, 2012
Available online at http://www.academicjournals.org/AJAR
DOI: 10.5897/AJAR12.020
ISSN 1991-637X ©2012 Academic Journals

Full Length Research Paper

Response of weed flora to conservation agriculture systems and weeding intensity in semi-arid Zimbabwe

Nester Mashingaidze[1]*, Ignacio Casper Madakadze[1] and Stephen Twomlow[2,3]

[1]Department of Plant Production and Soil Science, Faculty of Natural and Agricultural Sciences, University of Pretoria, Pretoria 0002, South Africa.
[2]International Crops Research Institute for the Semi-Arid Tropics, Matopos Research Station, P. O. Box 776, Bulawayo, Zimbabwe.
[3]IFAD Regional Office in Nairobi, C/O Union, UN Avenue, Kenya.

Accepted 6 April, 2012

A field study was conducted in the fifth (cowpea crop) and sixth (sorghum crop) seasons of a long-term conservation agriculture trial at Matopos Research Station to determine the effect of tillage, maize mulch rates and intensity of hoe weeding on weed density and community diversity. The experiment was a split-plot randomized complete block design with three replications. Tillage was the main plot factor; conventional tillage versus the minimum tillage (MT) systems of ripper tine and planting basins. Maize mulch rate (0, 4 and 8 t ha^{-1}) was the sub-plot factor to which was super-imposed the intensity of hoe weeding treatment (low and high) as from the fifth season. Tillage system had no significant (P<0.05) effect on weed density and diversity. Whereas the maize mulch rate of 4 t ha^{-1} increased weed density in both crops, the mulch rate of 8 t ha^{-1} decreased the density of *Portulaca oleracea* and *Corchorus tridens* in sorghum. Weed density was lower and community diversity higher in the high than the low weeding intensity treatment in sorghum. Although, frequent hoe weeding can be used to control weeds in MT systems, labour shortages may ultimately limit the area under MT in smallholder agriculture.

Key words: Tillage, maize mulch, weed density, community diversity, cowpea (*Vigna unguiculata* (L.) Walp.), sorghum (*Sorghum bicolor* (L.) Moench).

INTRODUCTION

The major biophysical constraints to rainfed crop production in the semi-arid areas of southern Africa are unreliable rainfall and infertile soils (Twomlow et al., 2006) with smallholder productivity further limited by poor crop management practices (Sanchez, 2002). Conservation agriculture (CA) based on the principles of minimum tillage, permanent organic soil cover and crop rotation is being currently promoted to smallholder farmers in southern Africa to increase productivity levels (FAO, 2010). Although, the majority of smallholder farmers face constraints in implementing full CA (Giller et al., 2009), there is increasing evidence that higher and more stable crop yields are being obtained in fields under minimum tillage compared to conventional ploughing (Wall, 2007). The minimum tillage systems of planting basin and ripper tines increased yield in semi-arid areas by enabling farmers with limited draught animal power to plant early, to use scarce soil fertility amendments more efficiently through precision application and to carry out timely crop management (Twomlow et al., 2009). However, the area under minimum tillage systems in southern Africa still remains low (Derpsch and Friedrich, 2009) with many arguing that the impacts of CA on crop production are extremely variable, dependent on soil type, crops and the initial weed infestation (Farooq et al., 2011; Gowing and Palmer, 2008; Giller et al., 2009).

Farooq et al. (2011) content that integrated weed management is the fourth component/principle of successful CA. This is because weed control is identified

*Corresponding author. E-mail: nestermash@yahoo.com. Tel: +263 712 933 329.

as the biggest and often most difficult challenge in management faced by farmers that adopt minimum tillage (Gowing and Palmer, 2008). In fact, in smallholder agriculture in Zimbabwe, conventional tillage such as mould board ploughing in early summer is considered a major weed control technique that prepares a weed-free seedbed for up to four weeks (Mabasa et al., 1998). Chauhan et al. (2006) reviewed tillage research mostly done in temperate regions and found that minimum tillage systems had higher weed density compared to conventional tillage. There is, also, mounting evidence of increased weed density under minimum tillage systems from research done in sub-Saharan Africa (Mabasa et al., 1998; Baudron et al., 2007). Furthermore, studies of minimum tillage systems indicated higher densities of perennial weed species in Zimbabwe (Vogel, 1994; Makanganise et al., 2001) compared to conventional tillage. These shifts to new and possibly more difficult to control weed species under minimum tillage systems is probably limiting the widespread uptake of CA by resource-poor farmers in Africa.

The adoption of minimum tillage has been mainly facilitated by the use of herbicides in developed countries and within the commercial farming sector in southern Africa (Wall, 2007). However, the affordability and availability of suitable herbicides limit their use in the smallholder farming sector of southern Africa (Giller et al., 2009). The majority of smallholder farmers use hand hoes to weed arable fields, a method that is slow, labour-intensive and associated with drudgery (Twomlow et al., 2006). Hoe weeding often results in a decrease in crop yield due to delayed weeding as labour is often unavailable during critical weeding periods (Gianessi, 2009). Consequently, the reported increases in labour required for hoe weeding crops under planting basins in Zambia (Baudron et al., 2007) and (Mazvimavi and Twomlow 2009), suggest that such minimum tillage systems are likely to exacerbate pre-existing weed control problems in the smallholder sector (Vogel, 1994). Since weed competition is one of the most serious and widespread problems (Gianessi, 2009) with weeds consistently ranked as the number one pest by smallholder farmers in sub-Saharan Africa (Sibuga, 1997), there is need to identify effective weed management strategies for use under smallholder minimum tillage systems if they are to be successfully promoted.

According to Wall (2007) and FAO (2010), weed control under CA is difficult only in the first years and becomes easier over time with good management. However, the ‘good weed management’ being referred to is achieved mainly through the use of herbicides (Wall, 2007). Although, the CA practices of crop residue mulching and crop rotation are reported to ameliorate weed problems under minimum tillage systems and lead to more sustainable weed management in the long-term (Wall, 2007; FAO, 2010), evidence of this from southern Africa is sparse and inconclusive (Gowing and Palmer, 2008; Giller et al., 2009). The aim of this study was to investigate the effects of tillage system, hoe weeding intensity and maize residue mulching on weed flora composition in the fifth and sixth years of a CA experiment in semi-arid Zimbabwe.

MATERIALS AND METHODS

Location

The field experiment was conducted at West Acre Creek of Matopos Research Station Farm (28° 30.92`E, 20° 23.32`S; 1 344 m above sea level) in southwestern Zimbabwe. The station is characterized by semi-arid climatic conditions (25.5°C average maximum and 10.7°C average minimum temperatures; and mean annual rainfall of 580 mm). The wet season is mainly confined to the period between November and March. The soil is a Chromic-Leptic Cambisol according to the FAO classification (Moyo, 2001) with a clay loam texture (41% clay, 20% silt, 38% sand), pH (water) of 6 and soil organic carbon of 1.2%.

Experimental design

A long-term conservation agriculture (CA) experiment was initiated in 2004 to determine soil water and crop responses to tillage and maize residue mulching (Mupangwa, 2009). The experiment was set up as a split-plot Randomised Complete Block Design with three replications. Tillage system was the main plot (63 x 6 m) factor and maize mulch rate the subplot (8 x 6 m) factor. The crop sequence was a three-year maize-cowpea-sorghum rotation with only one crop present per season.

At the commencement of this study in 2008, hand-hoe weeding intensity (low and high) was added as a treatment factor. The weeding intensity treatments were superimposed on maize mulch rates of 0, 4 and 8 t ha^{-1}, with each mulch rate replicated twice per tillage main plot (conventional tillage compared against the minimum tillage (MT) systems of planting basin and ripper tine). The high weeding intensity treatment was carried out a week before planting, 1 week after planting (WAP), at 5 WAP and before harvesting. This weeding regime was maintained from the previous four seasons and represented the CA recommendation of frequent weeding (Mazvimavi and Twomlow, 2009). The low weeding intensity treatment, done only a week before planting and at 5 WAP, simulated the smallholder farmer practice of planting into a clean seedbed after early summer mouldboard ploughing and then hoe weeding 40 or more days after planting (Twomlow et al., 2006).

Land preparation

In order to keep CA fields weed-free during the dry season as recommended by the Zimbabwean CA Taskforce (Twomlow et al., 2008), weeds were removed using hoes in June 2008 in the 2008/09 season and in June, August and September 2009 in the 2009/10 season. Although, most smallholder farmers do not traditionally hoe weed their fields in the dry season, the conventional (CONV) tillage plots in this study were also weeded at the same time as the MT plots. Under smallholder communal farming, free ranging livestock graze on weeds found in fields in the dry season such that the density of weeds and the seeds they set is likely to be lower than would be the case if weeds were left to grow and reproduce.

The MT systems were prepared on un-ploughed land in September of each year. Planting basins (PB) of 15 cm x 15 cm x 15 cm (length x width x depth) were dug using hand hoes at a row spacing of 90 cm with 60 cm between basins in a row. In the PB tillage system, only 11% of the total field surface areas were disturbed. In the ripper tine (RT) treatment, ripping was carried out using a commercially available ZimPlow® ripper tine attached to the beam of a donkey-drawn mouldboard plough. A depth of between 15 and 18 cm was achieved with rip lines spaced 90 cm apart. Of the total field surface area, 27% was disturbed in RT treatments. The positions of the basins and rip lines were maintained across the two seasons of this study, as had been done in the previous four seasons (Mupangwa, 2009). Conventional tillage was done each November on the first effective rains (50 mm) using a donkey-drawn ZimPlow® VS200 mouldboard plough and a ploughing depth of 15 cm was achieved.

Crop management

Cowpea (*Vigna unguiculata* L. cv. 86D719) was planted on the 26th of December, 2008. The cowpea was planted at a density of 74 074 plants ha^{-1} in PB and RT treatments, as per the Zimbabwean CA Taskforce guidelines (Twomlow et al., 2008) to give a density of 74 074 plants ha^{-1}. In CONV tillage, the recommended spacing of 60 cm x 25 cm was used to give a density of 67 667 plants ha^{-1}. Neither basal nor top dress fertilizer was applied to the cowpea based on the fact that most smallholder farmers do not apply any fertilizer to cowpea (Ncube, 2007). Hand hoe weeding was done according to the weeding intensity treatment during the cropping season. The cowpea crop was harvested in April, 2009.

In the 2009/10 season, cattle kraal manure (17.5% organic carbon, 0.13% N, 0.11% P) was applied in October, 2009 at a rate of 3 t ha^{-1}. Manure was spot applied into planting basins and banded along the rip lines. In CONV tillage plots, manure was banded along the planting furrows after ploughing. To check the manure for contamination with weed seeds, samples of the manure were assessed for the presence of weed seeds using the seedling emergence method of Rupende et al. (1998). Unlike observations made on manure from the smallholder sector (Rupende et al., 1998), no weed seedlings emerged in the eight months the manure was kept in the greenhouse. This suggests that the manure from the commercial herd at Matopos Research Station was free of viable weed seeds. Sorghum (*Sorghum bicolor* L. cv. Macia) was planted on the 2nd of December, 2009. In PB and RT plots, planting was done according to the CA guidelines (Twomlow et al., 2008) to give a sorghum population of 74 074 plants ha^{-1} in both tillage systems. In CONV tillage the recommended spacing of 75 cm x 20 cm was used to give a population of 88 889 plants ha^{-1}. During the cropping season, hoe weeding was done according to the weeding intensity treatments. Ammonium nitrate (34.5% N) was applied to the sorghum crop at a rate of 20 kg N ha^{-1} as topdressing at 5 WAP. The sorghum crop was harvested in April, 2010.

Data collection

Weeds were sampled at 1, 4, 9 and 13 WAP from a 0.5 m^2 quadrat thrown twice at random positions into each sub-plot. Weeds were identified to species level following Makanganise and Mabasa (1999) and counted. Stem counts replaced plant counts for perennial monocots. A number of grasses (*Setaria incrassata* (Hochst.) Hack; *Setaria pumila* (Poir.) Roem. and Schult; *Setaria verticillata* (L.) Beauv., and *Aristidia aspera)* was classified as *Setaria* spp due to difficulties in identifying them at the seedling stage.

Statistical analysis

Prior to analysis, weed density data was square root transformed (x + 0.5) to homogenize variances (Gomez and Gomez, 1984). Weed diversity was measured using weed species richness (number of species) and the Shannon-Weiner diversity and evenness indices. Shannon-Weiner' diversity index H' was calculated for each sub-plot after Magurran (1988) as follows:

$$H' = (N \ln N - \text{Sum } (n \ln n)) / N$$

Where H' measures species diversity through proportional abundance of species, with a higher value signifying greater diversity, N is the total population density m^{-2} and n is the population of each weed species found in this area; and evenness index E:

$$E = H' / \ln N$$

Where E is the relationship between the observed number of species and total number of species, with a greater value indicating greater uniformity between species abundances.

The analysis of the weed density and diversity data was performed separately for each season (crop). The data were subjected to the analysis of variance using GenStat Release 9.1 (Lawes Agricultural Trust 2006). The treatment and interaction standard error of differences (SED) of the means from split-plot ANOVA were used to separate treatment means at 5% level of significance.

RESULTS AND DISCUSSION

Seasonal rainfall

Although the 2008/09 cropping season received 11% more rainfall between November and March (day 0 to 150) than the 2009/10 season, the rains were poorly distributed (Figure 1). The month of December 2008 was characterized by low rainfall which fell towards the end of the month resulting in the cowpea crop being planted late. In contrast, January 2009 was very wet, receiving almost half of the total rainfall of the 2008/09 season (Figure 1A). The incessant rains in January 2009 resulted in poor weed control such that hoe weeding had to be repeated (weeding 3a and 3b) within the same month to reduce weed infestations in all treatments. In the 2009/10 season, the high rains received in December 2009 enabled sorghum to be planted early. There was a more even rainfall distribution in this season compared to the 2008/09 season (Figure 1).

General effects on weed species and density

The weed species identified and the significant treatment effects of tillage, maize mulch rate and weeding intensity on individual weed species density and community diversity in cowpea and sorghum crops are summarized in Tables 1 to 5. There was no significant ($P<0.05$) tillage x maize mulch rate x weeding intensity interaction on weed composition in both crops. The tillage x maize mulch rate interaction was significant ($P<0.05$) for the density of *Leucas martinicensis*, *Setaria* spp and *Urochloa panicoides* in cowpeas during the 2008/09

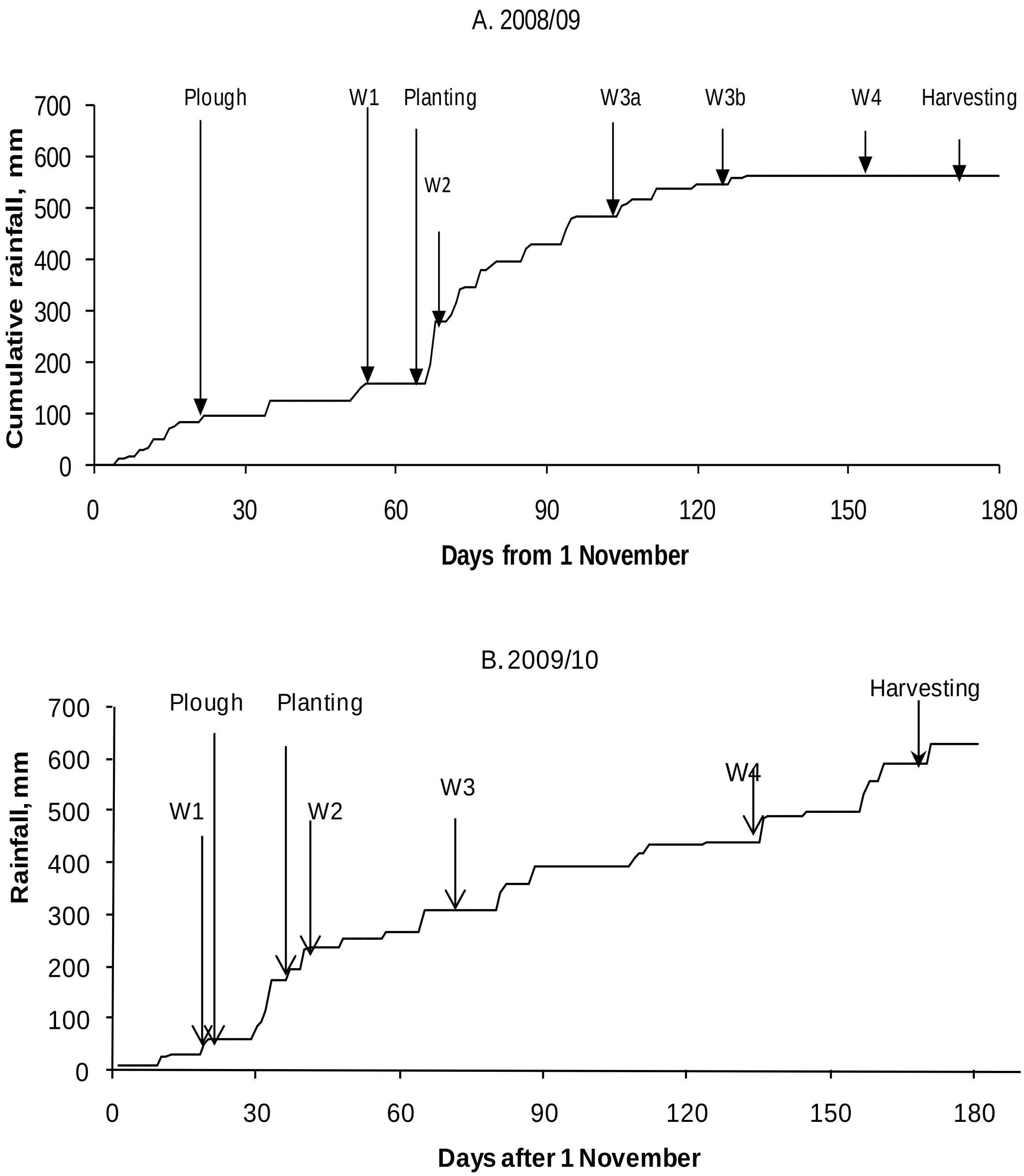

Figure 1. Cumulative daily rainfall received and the timing of crop management practices at Matopos Research station during the A. 2008/09 (561.1 mm) and B. 2009/10 (590.5 mm) cropping seasons. W1, W2, W3 and W4: high intensity hoe weeding operations; W1 and W3: low intensity hoe weeding operations.

season and *Boerhavia diffusa* and *Schkuria pinnata* in sorghum during the 2009/10 season (Figure 2). There was a significant (*P<0.05*) tillage x weeding intensity interaction on the density of *Argemone mexicana*, *Cleome monophylla* and *Malva verticillata* in cowpeas during 2008/09 season and *A. mexicana*, *Bidens pilosa* and *U. panicoides* in sorghum during the 2009/10 season (Figure 3). The maize mulch rate x weeding intensity interaction was significant (*P<0.05*) for the density of *Ipomea plebia*, *S. pinnata* and *Setaria* spp (Figure 4) and annual monocots (Figure 5) in sorghum grown during the 2009/10 season. These interactions are discussed below in detail under the respective subtitles.

Specific weed densities

Twenty-six weed species were identified in the cowpea phase in the first 13 weeks after planting (Table 1). Of these, twenty-four were also found among the twenty-five

Table 1. Mean density of weed species (no. m^{-2}) found in the first 13 weeks in cowpea and sorghum crops grown at Matopos Research Station during the 2008/09 and 2009/10 seasons, respectively.

Life cycle	Latin binomial	Mean density m^{-2} (N = 54)	
		Cowpea (2008/09)	Sorghum (2009/10)
Annual dicots		87.3	123.7
	Acalypha crenata Hochst. Ex. A. Rich.	2.4	1.8
	Acanthospermum hispidum DC.	0.1	0.02
	Alternanthera repens (Linnaens) Link	10.9	15.9
	Amaranthus hybrius L.	0.7	0.8
	Argemone mexicana L.	2.0	0.2
	Bidens pilosa L.	1.2	7.3
	Cleome monophylla L.	0.4	0.1
	*Conyza albida (*Retz.) E.H. Walker	2.9	0.4
	Corchorus tridens L.	10.0	11.1
	Datura stramonium L.	0.1	0.4
	Euphorbia prostrata	0.2	17.8
	Gnaphalium pensylvanicum Willd	6.3	-
	Ipomea plebia L.	0.04	0.2
	Leucas martinicensis (Jacq.)R.Br.	42.4	53.9
	Malva verticillata L.	0.1	-
	Portulaca oleracea L.	3.1	8.2
	Schkuria pinnata (lam.) Thell.	2.1	1.6
	Sonchus oleraceus L.	1.1	3.4
	Tagetes minuta L.	1.2	3.4
Annual monocots		101.7	139.9
	Commelina benghalensis L	13.9	18.5
	Eleusine indica (L.) Gaertn.	4.3	3.5
	Setaria spp	87.7	110.5
	Urochloa panicoides Beauv	0.8	7.4
Perennial dicot		3.6	3.7
	Boerhavia diffusa L	3.6	2.6
	Sida alba L.	-	1.1
Perennial monocot		2.2	7.0
	Cynodon dactylon (L.) Pers.	1.8	1.3
	Cyperus esculentus L.	0.4	0.1
	Total	194.8	274.3

weed species identified in the sorghum phase the following season. Of the 27 weed species identified during the two years of the study, all the monocot weed species were present in both seasons. However, the perennial dicot *Sida alba* was absent in the 2008/09 season and the annual dicots *Gnaphalium pensylvanicum* and *Malve verticillata* were absent in the 2009/10 season. The density of most weed species varied with season probably reflecting the differences between the two seasons in terms of precipitation (Figure 1) and the conditions required by the different weed species for growth under the different stages of the rotation.

Annual weed species made up over 95% of the weed community with annual monocots being the most abundant weed group in both crops (Table 1). The dominant weed species in the two crops were *Setaria* spp, *L. martinicensis* and *C. benghalensis*. However, in sorghum these species only comprised 67% of the weed community compared to 71% in cowpeas. The weed *E. prostrata* that was a minor weed in cowpea (0.1% of community) increased in density in sorghum (6.5% of community) to become the fourth most abundant weed in the community. In addition, weed density (m^{-2}) under sorghum was 41% higher than under cowpea.

Table 2. Effect of tillage on density of weed species[a] found in cowpea (2008/09 season) and sorghum (2009/10 season) at Matopos Research Station.

Weed species	Weed density (m^{-2})							
	Cowpea				Sorghum			
	Tillage system (N =18)				Tillage system (N =18)			
	CONV	RT	PB	SED	CONV	RT	PB	SED
A. crenata	2.1	1.0	1.2	0.27	1.8	1.1	1.0	NS
C. tridens	4.0	2.4	2.3	0.30	3.8	3.0	2.9	NS
P. oleracea	1.4	2.0	1.9	0.15	2.8	2.6	2.6	NS
S. pinnata	1.0	1.4	1.4	NS	0.8	1.3	1.4	0.16
S. alba	-	-	-		1.5	1.0	0.8	0.14
Total density	14.5	13.7	13.3	NS	14.8	17.0	15.9	NS

[a] weed species that had a significant response to treatment in at least one crop; CONV: Conventional mouldboard plough, RT: ripper tine, PB: Planting basin; SED, standard error of the difference between mean values; NS, not significantly different (P>0.05); Square root (*x*+0.5) transformed data presented with value of 0.7 = 0 untransformed data.

Table 3. Effect of maize mulch rate on density of weed species[a] found in cowpea (2008/09 season) and sorghum (2009/10 season) at Matopos Research Station.

Weed species	Weed density (m^{-2})							
	Cowpea				Sorghum			
	Mulch rate t ha^{-1} (N =18)				Mulch rate t ha^{-1} (N =18)			
	0	4	8	SED	0	4	8	SED
G. pensylvanicum	1.8	2.7	2.7	0.23	-	-	-	
C. albida	1.2	1.7	2.1	0.26	0.9	0.8	0.9	NS
C. tridens	3.5	3.0	2.8	NS	3.9	3.2	2.7	0.32
B. diffusa	2.2	1.6	1.7	NS	1.7	1.3	1.7	0.18
E. indica	1.4	2.3	2.3	0.32	1.6	1.7	1.9	NS
E. prostrata	0.8	0.8	0.7	NS	4.8	3.6	2.9	0.46
L. martinicensis	5.4	7.3	5.3	0.63	4.8	8.0	6.5	0.90
P. oleracea	1.9	1.7	1.6	NS	2.9	3.0	2.2	0.29
S. pinnata	0.9	1.1	1.8	0.29	0.7	1.0	1.8	0.15
Setaria spp	8.6	9.1	9.0	NS	9.3	11.1	8.8	0.59
Annual dicot	8.3	10.1	9.0	0.57	10.5	11.5	10.2	NS
Annual monocot	9.4	10.2	10.1	NS	10.5	12.3	10.5	0.69
Perennial dicot	2.2	1.6	1.7	NS	2.0	1.6	1.9	NS
Perennial monocot	1.4	1.0	1.0	NS	2.1	0.9	1.8	NS
Total	13.0	14.6	13.9	0.39	15.7	17.0	15.0	0.66

[a] weed species that had a significant response to treatment in at least one crop; SED, standard error of the difference between mean values; NS, not significantly different (*P>0.05*); Square root (*x*+0.5) transformed data presented with value of 0.7 = 0 untransformed data.

The majority of annual weed seeds requires light for germination and may have benefited from increased light penetration under the more open sorghum canopy. Sorghum is reported to grow slowly early in the cropping season with maximum growth occurring before or after anthesis (Traor`e et al., 2003), which occurred nine weeks after planting for the sorghum crop in this experiment. In contrast, the semi-erect cowpea varietyused in this study was observed to grow fast and cover the ground earlier than sorghum. The fast canopy development in cowpea probably resulted soil shading and suppression of weed germination. Based on these observations, the use of competitive crops or cultivars is one of the strategies that can be used by resource-poor farmers to suppress growth of annual weed species early in the cropping season.

Tillage effect

Tillage had no significant (P>0.05) effect on the total

Table 4. Effect of intensity of hand-hoe weeding on density of weed species[a] found in cowpea (2008/09 season) and sorghum (2009/10 season) crops at Matopos Research Station.

Weed species	Weed density (m^{-2})					
	Cowpea			Sorghum		
	Weeding intensity (N = 27)			Weeding intensity (N = 27)		
	Low	High	SED	Low	High	SED
S. oleraceus	1.2	0.9	0.09	1.0	0.9	NS
A. repens	2.6	2.6	NS	4.2	2.8	0.47
A. mexicana	1.2	1.2	NS	0.9	0.7	0.05
B. pilosa	1.1	1.1	NS	2.6	1.7	0.27
C. benghalensis	3.2	2.6	NS	4.9	2.8	0.38
E. indica	1.5	1.2	NS	2.1	1.4	0.28
L. martinicensis	5.0	4.8	NS	8.3	4.6	0.62
S. pinnata	1.2	1.2	NS	1.4	1.0	0.14
Setaria spp	8.7	8.3	NS	12.4	7.0	0.56
U. panicoides	0.9	0.8	NS	2.9	2.0	0.30
Annual dicot	9.4	8.9	NS	12.8	8.7	0.47
Annual monocot	10.2	9.6	NS	14.1	8.1	0.69
Perennial dicot	1.8	1.8	NS	1.5	1.6	NS
Perennial monocot	1.0	1.2	NS	1.8	1.4	NS
Total	14.2	13.5	NS	19.4	12.4	0.59

[a]weed species that had a significant response to treatment in at least one crop; SED, standard error of the difference between mean values; NS, not significantly different (P>0.05); Square root (x+0.5) transformed data presented with value of 0.7 = 0 untransformed data.

Table 5. Richness (number of species per plot), diversity (Shannon's H' index) and evenness (Shannon's E index) for weed species present under different treatments in cowpea (2008/09 season) and sorghum (2009/10 season) crops grown at Matopos Research Station.

Treatment	Cowpea weed diversity indices			Sorghum weed diversity indices		
	Richness	Diversity	Evenness	Richness	Diversity	Evenness
Tillage						
CONV	11.4	1.48	0.61	13.2	1.73	0.68
RT	12.1	1.63	0.66	13.2	1.78	0.68
PB	11.6	1.63	0.67	12.4	1.73	0.71
P-value	0.793	0.214	0.277	0.617	0.863	0.738
SED	NS	NS	NS	NS	NS	NS
Mulch t ha^{-1}						
0	11.1	1.55	0.65	12.9	1.81	0.71
4	12.2	1.56	0.63	12.2	1.61	0.65
8	11.9	1.62	0.66	13.1	1.83	0.70
P-value	0.201	0.595	0.534	0.099	0.024	0.062
SED	NS	NS	NS	NS	0.077	NS
Weeding intensity						
Low	12	1.6	0.65	13.6	1.7	0.65
High	11.5	1.56	0.64	12.2	1.8	0.72
P-value	0.376	0.586	0.823	0.02	0.052	0.001
SED	NS	NS	NS	0.55	NS	0.017

CONV: Conventional mouldboard plough, RT: ripper tine, PB: Planting basin; SED, standard error of the difference between mean values; NS, not significantly different (P>0.05).

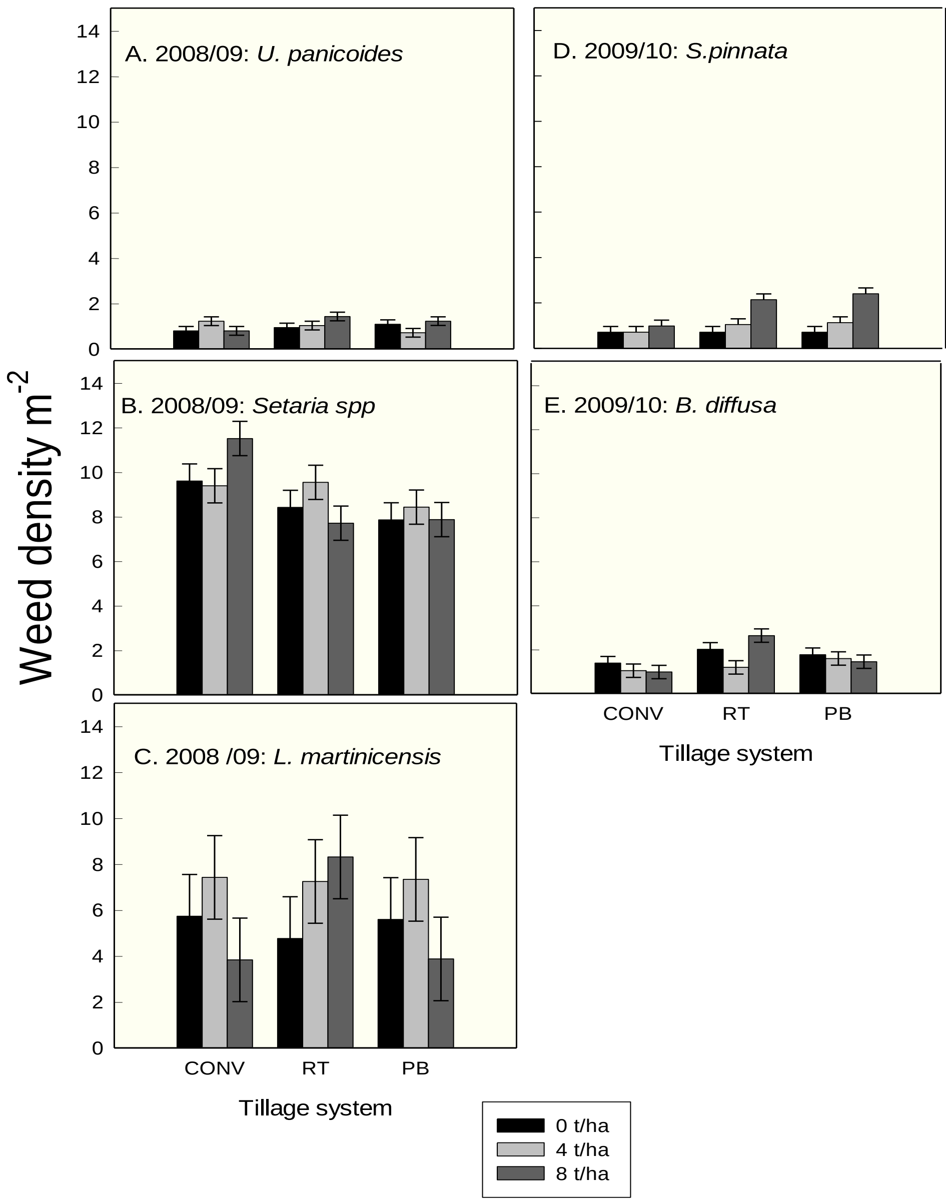

Figure 2. Tillage x maize mulch rate interaction on total density of A. *U. panicoides*, B. *Setaria* spp and C. *L. martinicensis* in cowpea (2008/09) and D. *S. pinnata* and E. *B. diffusa* in sorghum (2009/10) grown at Matopos Research Station. Bars represent ± SED.

weed density in both cowpea and sorghum crops (Table 2). Conventional tillage was associated with significantly (P<0.05) greater densities of *A. crenata* and *C. tridens* than the MT systems in cowpea. Although not statistically significant, a similar trend was observed for the two weed species in sorghum. The density of *S. alba* was significantly (P<0.05) higher in CONV tillage than in MT systems in sorghum (Table 2). The weed *C. tridens* is characterized by a high degree of dormancy with germination increasing with seed coat scarification (Dzerefos et al., 1994). Weed species such as *C. tridens* that require burial in order to germinate may, therefore, be favoured in CONV tillage and decline in MT systems where there is no soil inversion. Such species survive soil burial by undergoing dormancy which is broken when the seeds encounter suitable conditions when they are brought to the soil surface through subsequent ploughing events.

A significantly (P<0.05) higher density of *P. oleracea* was found under MT systems than CONV tillage in cowpea (Table 2). A similar significant (P<0.05) trend was observed for *S. pinnata* in sorghum where weed density was 38% higher under MT systems than CONV tillage. The weed species *P. oleracea* is small seeded

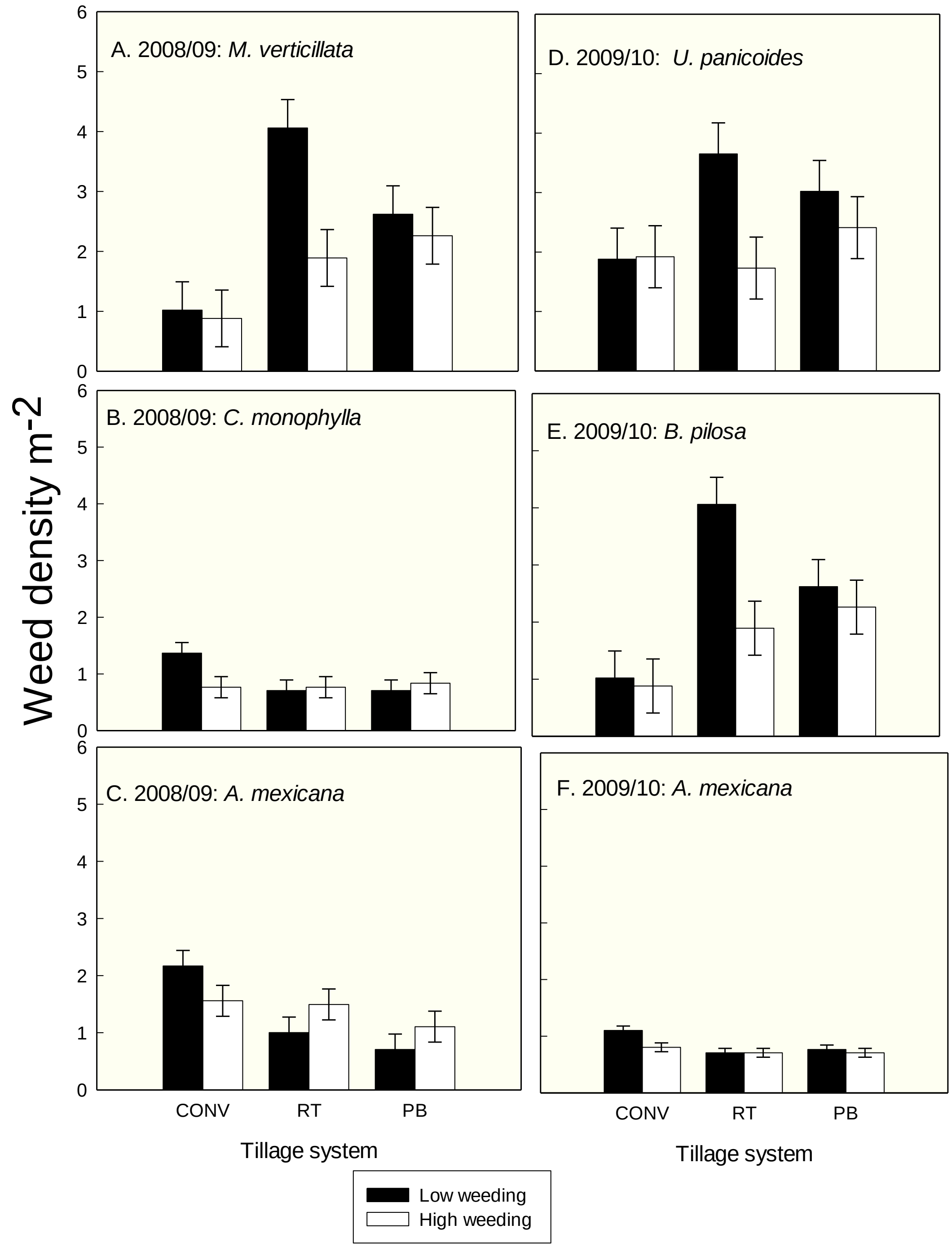

Figure 3. Tillage x weeding intensity interaction on total density of A. *M. verticillata*, B. C. *monophylla* and C. *A. Mexicana* in cowpea (2008/09) grown and D. *U. panacoides*, *E. B. pilosa* and *F. A. mexicana* in sorghum (2009/10) grown at Matopos Research Station. Bars represent ± SED.

(Makanganise and Mabasa, 1999) and is likely to be more sensitive to light than large seeded weeds (Chauhan et al., 2006) such as *C. tridens.* Small seeded weed species may, therefore, benefit from the low seed burial and exposure of seed to light under MT systems. Chauhan and Johnson (2009) also observed that *P. oleracea* emergence was greater under zero till than under conventional tillage. The ability of *P. oleracea* to survive for some time after being uprooted then setting root and producing new plants under moist conditions makes it difficult to eradicate by cultivation. This species, therefore, has the potential to become a serious weed in

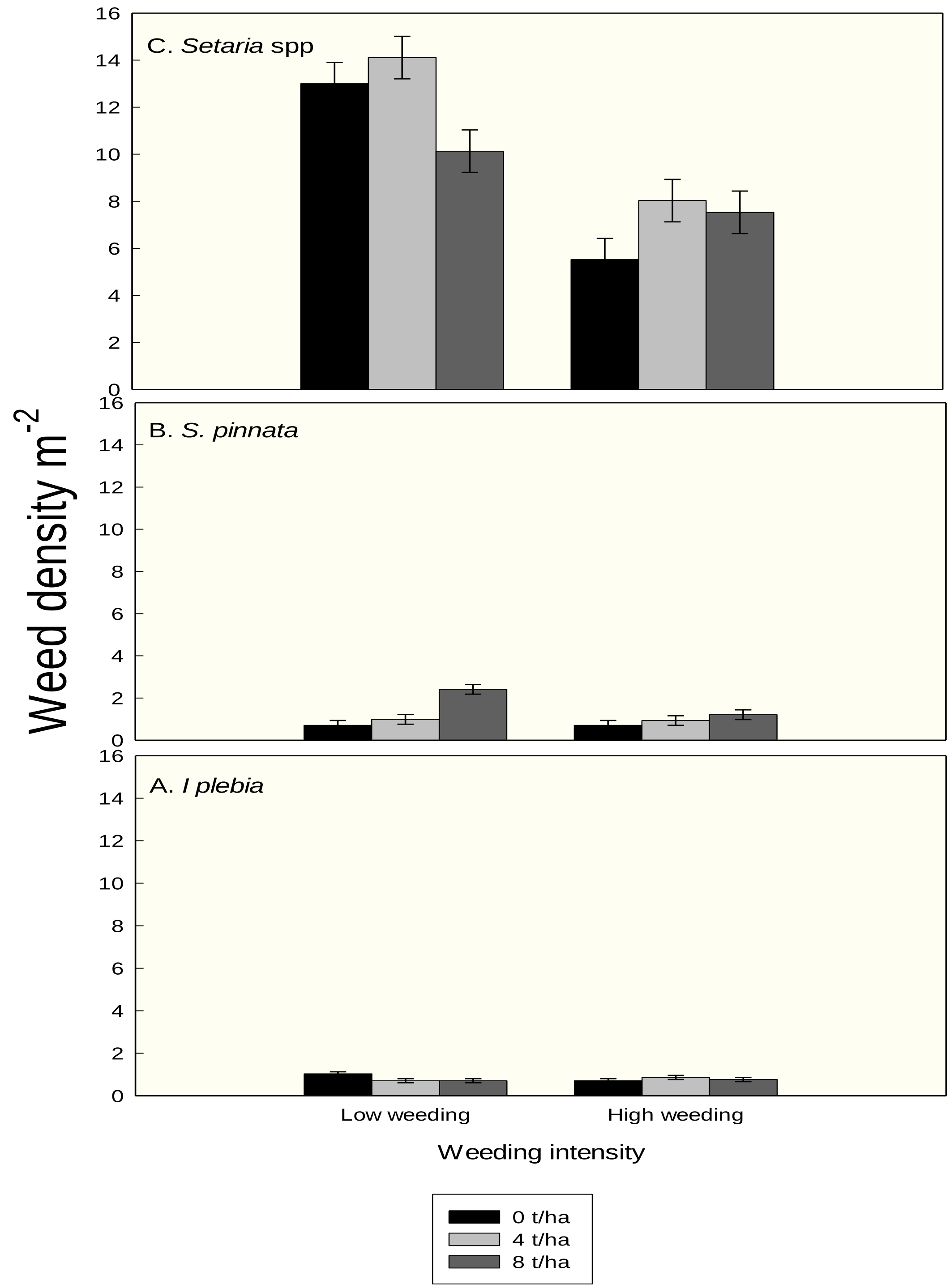

Figure 4. Maize mulch rate x weeding intensity interaction on total density of A. *I. plebia,* B. *S. pinnata* and *C. Setaria* spp in sorghum grown at Matopos Research Station. Bars represent ± SED.

MT systems especially for resource-poor farmers without access to pre-emergence herbicides.

Maize mulch effect

Mulching was generally associated with an increase (P<0.05) in weed density compared to the un-mulched treatment in both the cowpea and sorghum crops. Retaining maize residue as surface mulch significantly (P<0.05) increased the density of *C. albida, E. indica, G. pensylvanicum*, *L. martinicensis* and *S. pinnata* under cowpea and *L. martinicensis*, *S. pinnata* and *Setaria* spp

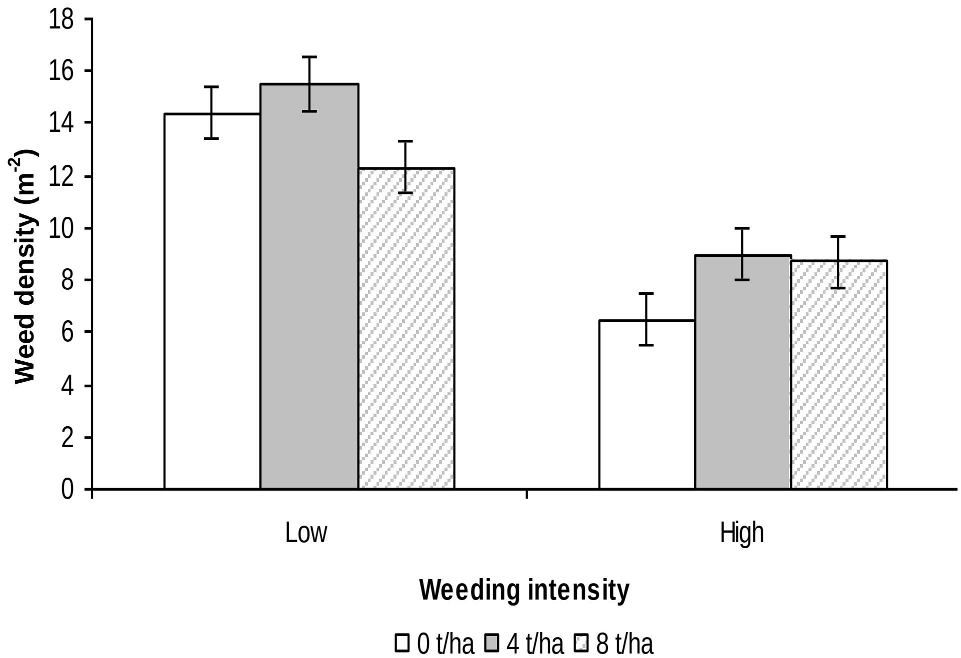

Figure 5. Maize mulch rate x weeding intensity interaction on total density of annual monocot species found in sorghum grown during the 2009/10 season at Matopos Research Station. Bars represent ± SED.

under sorghum (Table 3) in this study. The changes in soil temperature, moisture, light availability and soil nitrate levels on crop residue mulching (Christofolleti et al., 2007) probably created conditions favourable for the germination of some weed species. If the maize mulch resulted in moisture conservation as was previously reported by Mupangwa (2009) at the same site, this may have increased the germination and growth of species such *C. albida* and *G. pensylvanicum* that are commonly found in damp places. In addition, the maize residue may have trapped seeds of wind-dispersed weed species such as *C. albida* and *L. martinicensis* which later germinated and increased the density of these weed species under the mulch treatment.

For some weed species, the increase in density on mulch retention was specific to a tillage system. Of interest was the significant (P<0.05) increase in weed density observed on mulching in MT systems for *L. martinicensis, Setaria* spp and *U. panicoides* in the cowpea phase of the rotation and for *S. pinnata* and *B. diffusa* in the sorghum phase (Figure 2). The association of *S. pinnata* with MT systems (Table 2) and mulching suggests that this weed is likely to be found in greater densities under CA than CONV tillage. However, the weed is easily controlled by mechanical methods including hoe weeding and is, thus, unlikely to emerge as a problem weed in CA.

The intermediate maize mulch rate of 4 t ha^{-1} had the highest density (P<0.05) of *L. martinicensis,* and increased annual dicot weed density by 18% and total weed density by 11% (P<0.01) compared to the un-mulched treatment in the cowpea crop. A similar significant (P<0.05) trend was observed in the sorghum crop for *P. oleraceae*, *Setaria* spp and *L. martinicensis* with increases in annual monocots (15%) and total weed density (8%) at 4 t ha^{-1} maize mulch rate relative to where no mulch was retained (Table 3). In most cases, a lower weed density was observed under the maize mulch rate of 8 t ha^{-1} than the 4 t ha^{-1} maize mulch rate. This may have been due to a reduction in seed germination due to increased shading of the soil under the thicker layer of mulch at 8 t ha^{-1}.

The presence of maize residue at rates of 4 and 8 t ha^{-1} on the soil surface was also associated with weed suppression in some species. Reduced weed density on mulching was observed only in sorghum where significant (P<0.05) suppression was observed across all tillage systems in the densities of *C. tridens*, *P. oleracea* and *E. prostrata* (Table 3) and under ripper tine for *B. diffusa* (Figure 3). Chauhan and Johnson (2009) also observed that *P. oleracea* seedling emergence declined exponentially with increased rates of rice residue. Crop residue mulch has been reported to reduce light transmittance and daily soil temperature amplitude which can lead to weed seed germination reduction or inhibition (Christofolleti et al., 2007).This may be the reason for the lower weed density of some species under the maize mulch in the sorghum crop. In addition, for small seeded weed species like *P. oleracea* the maize mulch may have acted as a physical barrier to weed seedling emergence and growth. For *C .tridens* and *P. oleracea* a significant reduction in density was observed only at a maize mulch rate of 8 t ha^{-1}. However, smallholder farmers in semi-arid areas are unlikely to retain even the lower maize reside rate (4 t ha^{-1}) due to the current low cereal residue yields and their important use as livestock feed in mixed crop-livestock systems.

In this study, the effect of the maize mulch on weed density varied with species, crop grown (Table 3) and for some species with tillage system (Figure 2) which makes it impossible to make generic conclusions. According to Farooq et al. (2011), generalised statements about CA are often inappropriate because the effect of CA components is in most cases site specific with interactions between CA components common. Weed suppression on maize residue mulching was observed for some weed species, but not all, and only under the sorghum phase of the rotation. For species such as *P. oleracea* that had high densities under MT systems (Table 2), mulching as is being promoted under CA can be a weed control strategy. However, retaining 4 t ha^{-1} or more of maize residue for suppression of four out of twenty five weed species with no overall decrease in weed density is unlikely to be a practice that is adopted by smallholder farmers. Maize mulching was, however, observed to increase the density of problematic weeds species such as *E. indica* in the cowpea phase of the rotation (Table 3) which is reported to be the most aggressive weed in Zimbabwe (Makanganise and Mabasa, 1999). The marked increase in total weed density in general and of specific problem weeds especially at the maize mulch rate of 4 t ha^{-1} is likely to exacerbate smallholder farmers' weed management problems. In fact, maize mulching was associated with decreased sorghum grain yield in the 2009/10 cropping season probably as a result of high weed growth under mulch (Mashingaidze et al., 2012).

Intensity of hoe weeding effect

The high weeding intensity significantly (P<0.001) reduced total weed density, the density of annual dicots by 31% and annual monocots by 43% in the sorghum crop (Table 4).

The higher density of annual weeds observed in the low weeding intensity treatment in sorghum may be due to the fact that a greater seed returns to the soil seed bank under cowpea.

During the cowpea phase of the rotation, the shorter weeding period in the low weeding intensity probably allowed most of the late season annual weeds to produce seed and add to the soil reservoir.

Doubling the number of hoe weeding operations within the cropping season significantly (P<0.05) decreased the density of *S. oleraceus* in the cowpea crop and of *A. repens, A. mexicana*, *B. pilosa*, *C. benghalensis*. *E. indica*, *L. martinicensis, S. pinnata*, *Setaria* spp and *U. panicoides* in the sorghum phase of the rotation (Table 4). However for some species in both crops, the effect of weeding intensity was confounded within the significant (P<0.05) tillage* weeding intensity interaction (Figure 3).

The density of *C. monophylla* in the cowpea crop and *A. mexicana* in both crops was reduced in the high weeding treatment than in low weeding intensity only under CONV tillage (Figure 3B, C and F). On the other hand, the high weeding intensity treatment in the RT system reduced the density of *M.* verticillata in cowpea crop and of *U. panicoides* and *B. pilosa* in the sorghum crop compared to the low weeding intensity treatment (Figure 3 A, D and E).

In addition, the effect of the intensity of hoe weeding was confounded within the significant (P<0.05) maize mulch rate * weeding intensity for *I.* plebia, *S. pinnata* and *Setaria* spp in the sorghum crop (Figure 4). The density of *I. plebia* was reduced on mulching only in the low weeding treatment (Figure 4A). The significant (P<0.01) interaction for *S. pinnata* showed that the high weed density at 8 t ha^{-1} (Table 3) was found only under the low weeding intensity treatment (Figure 4B). On the other hand, the high *Setaria* spp density on maize mulching in sorghum (Table 3) was found under the high weeding intensity treatment (Figure 4C).

In contrast, under the low weeding intensity treatment, there was significant suppression of *Setaria* spp at the maize mulch rate of 8 t ha^{-1}. A similar trend was observed for the annual monocots in the sorghum crop (Figure 5) which was not surprising as *Setaria* spp was the dominant weed in this group comprising 90% by density. The results from the annual monocots and *I. plebia* suggest that mulching may be a useful strategy for reducing the density of these weeds species under low weed management conditions.

In agreement with the findings of Gianessi (2009), timely and frequent weeding reduced weed infestations in all tillage practices in this study. The stronger responses of weed species density to weeding intensity and maize mulching than to tillage system suggests that these had a stronger effect on weed seed germination and emergence than tillage. Booth and Swanton (2002) also noted that weed management methods such as herbicide application are a stronger constraint to community assembly than tillage intensity. Based on the findings of this study frequent and timely hoe weeding was effective in reducing weed density and should, therefore, be encouraged in MT systems of resource-poor smallholder farmers until alternative weed management regimes such as herbicides become possible. However, it is worth noting that the requirement for a high weeding frequency in CA as observed in this study has been cited by smallholder farmers in southern Africa as the main constraint to expansion of the area under CA-based tillage systems (Baudron et al., 2007).

Weed community diversity

Tillage had no significant effect on species richness, Shannon' diversity (H) and evenness (E) indices in both the cowpea and sorghum phases of the rotation (Table 5); these results are consistent with the findings of Legere et al. (2005). This lack of an increase in weed diversity with reduction in soil disturbance can be attributed to the confounding effect of other agronomic and environmental factors. Weed diversity indices in this study were low ($H^{'}$ < 2.0) and similar to indices recorded in maize fields in eastern Zimbabwe by Manduna-Madamombe et al. (2008). The evenness index values suggest little evidence of dominant weed species in any of the tillage systems.

Although, there were changes in the density of some weed species on maize mulching (Table 3), the number of weed species in the communities did not vary in both crops (Table 5). However, in sorghum the intermediate maize mulch rate of 4 t ha^{-1} had the least diverse (P<0.05) weed community and the lowest weed species evenness (Table 5). The weed community under the 4 t ha^{-1} maize mulch rate had a higher proportion of *Setaria* spp and *L. martinicensis* which were the two most dominant species in the weed communities under the mulch treatments. These weed species probably took advantage of the improved soil surface conditions for germination under the intermediate mulch rate as reflected by the associated high weed density under this mulch rate (Table 3). The *Setaria* spp group is one of the worst weed groups in the world and competes for resources efficiently resulting in the exclusion of other weed species (Dekker, 2003).

The low weeding intensity treatment was associated with a significantly (P<0.05) higher number of weed species than that observed at the high weeding intensity across all the tillage systems in sorghum (Table 5). This suggests that more weed species were able to emerge and grow successfully in the low weeding intensity treatment than in the high weeding intensity treatment. This is consistent with the findings of Legere et al. (2005) who noted that weed diversity indices are more consistently affected by weed management. However, in our study the individual weed species in the weed community under the low weeding intensity treatment were less (P<0.01) evenly distributed resulting in a less diverse weed community (Table 5). The density of abundant weed species such as *Setaria* spp, *L. martinicensis* and *A. repens* were higher in the low weeding intensity treatment compared to high weeding intensity resulting in these species being more dominant in the low intensity community. The low weeding intensity treatment is a reflection of the current smallholder farmers' weeding practices. The less diverse community under the low weeding intensity treatment may result in weed management problems. According to Miyazawa et al. (2004), high weed community diversity may facilitate weed control in sustainable agriculture by enhancing competition among weed species and preventing the dominance of a single weed species, especially if this is a problem weed in arable fields.

Conclusion

Weed density and community diversity in the MT systems of planting basin and ripper tine did not vary significantly from that under CONV tillage at Matopos Research Station, even after five or six years. Minimum tillage systems had, however, high numbers of the small-seeded weed species *P. oleracea* in the cowpea phase and *S. alba* in the sorghum phase. The intermediate maize residue rate of 4 t ha^{-1} had the highest weed density in both crops; the least diverse weed community dominated by *Setaria* spp and was associated with increased density of aggressive weeds such as *I. indica*. Our findings suggest that moderate mulch rates may exacerbate the weed management problems of small holder farmers. However, the mulch rate of 8 t ha^{-1} reduced the density of C*. tridens*, *P. oleraceae*, and *E. prostrata* in the sorghum crop. Furthermore, mulching in general for *I. plebia* and the maize mulch rate of 8 t ha^{-1} for annual monocots were observed to suppress weed density under the low weeding intensity treatment suggesting that mulching can supplement hoe weeding where frequent weeding is not possible for these weed species. The high hoe weeding intensity treatment reduced weed density and species richness under sorghum, and had a more diverse weed community than the low weeding intensity treatment. The findings of this study suggest that frequent hoe weeding can effectively control weeds even in MT systems. However, this high weeding requirement may ultimately limit the area cropped under MT systems.

ACKNOWLEDGEMENTS

We would like to thank the Department for International Development of the United Kingdom (DFID-UK), the International Foundation for Science (IFS) and National Research Foundation (NRF, South Africa) for providing funding for this study.

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