CHAPTER 4

RESPONSE OF WEED FLORA TO CONSERVATION AGRICULTURE SYSTEMS AND WEEDING INTENSITY IN SEMI-ARID ZIMBABWE

ABSTRACT

The perception that minimum tillage systems are associated with increased weed pressure and more difficult to manage weed species may be limiting adoption of CA among smallholder farmers in southern Africa most of whom have limited access to herbicides. A field study was conducted in the fifth (cowpea crop *Vigna unguiculata cv.* IT 86D-719) and sixth (sorghum crop *Sorghum bicolor cv.* Macia) seasons of a long-term conservation agriculture trial at Matopos Research Station (28^0 30.92`E, $20^0$ 23.32`S) to determine the effect of tillage, maize mulch rates and intensity of hoe weeding on weed species 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 community diversity although MT systems were associated with small seeded weed species such as *Portulaca oleracea* that may have benefited from shallow seed placement. Retaining moderate quantities of maize mulch may exacerbate smallholder weeding burden as the maize mulch rate of 4 t ha^{-1} had the highest weed density in both crops and a community dominated by the problematic *Setaria* spp. and *Elusine indica* in the sorghum phase of the rotation. However, the highest maize mulch rate (8 t ha^{-1}) reduced density of *P. oleracea* and *Corchorus tridens* at the low weeding intensity 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, hoe weeding intensity, weed diversity, cowpea, sorghum

4.1 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).

Farooq *et al*. (2011) contend that integrated weed management is the fourth component / principle of successful CA. This is because weed control is identified as the biggest and often most difficult challenge in management faced by farmers that adopt minimum tillage (Gowing & Palmer, 2008). A review done by Chauhan *et al*. (2006a) 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 who lack access to herbicides.

However, according to literature on CA, adverse changes in weed species composition are limited under recommended CA practices (FAO, 2010). The weed composition changes that occur under CA instead result in a more diverse weed community that is easy to manage. This is attributed to the simultaneous practice of MT, crop residue mulching and crop rotation that diverse the selection pressure on weeds and thereby minimise the emergence of a dominant weed species that may prove to be difficult to control. There is no research regarding the impact of tillage systems and maize residue mulching on weed communities in medium-term CA where weeds are managed using hoe weeding.

The specific objectives were:

1. To determine the effect of tillage and maize mulch rate on weed species composition and weed community diversity;
2. To investigate the effect of hoe weeding intensity on the composition of weed species in the community under CA.

4.2 MATERIALS AND METHODS

4.2.1 Experimental design and crop management

The experimental design and agronomic management were as presented in Chapter 3.

4.2.2 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 as described in Chapter 3. 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. & Schult; *Setaria verticillata* (L.) Beauv., and *Aristidia aspera)* was classified as *Setaria* spp. due to difficulties in identifying them at the seedling stage.

4.2.3 Statistical analysis

Square root (x + 0.5) transformed cumulative weed density measured between 1 and 13 WAP for each species was subjected to ANOVA (GenStat 9.1). The analysis of the weed density and diversity data was performed separately for each season (crop). The treatment and interaction least significant differences (LSD) of the means from split-plot ANOVA were used to separate treatment means at 5% level of significance.

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:

$$H' = (N \ln N - \mathit{Sum}\ (n \ln n)) / N \qquad \textit{Equation 1}$$

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

$$E = H' / \ln N \qquad \textit{Equation 2}$$

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.

4.3 RESULTS AND DISCUSSION

4.3.1 Seasonal rainfall

Rainfall distribution varied between the 2008/09 and 2009/10 season with an more even rainfall distribution experienced in the second season (Fig. 4.1). At Matopos, the period between October and March has a 70-year mean rainfall of 533 mm with on average 242 mm received between October and December and 291 mm falling within the last half of the season (Mupangwa, 2009). No rainfall was recorded in October of both seasons. The rainfall distribution during the 2008/09 cropping season differed widely from the average season at Matops in that about 72% of the seasons rainfall fell between January and March with most of the rainfall concentrated between day 67 and 73 (Fig. 4.1A). In contrast, the first half of the 2008/09 season was quite dry receiving 35% less rainfall than the average season. Rainfall in the 2009/10 season was more evenly distributed between the two halves of the season although the rainfall received in the second half of the season was 20% less than the average rainfall received between January and March at this site (Fig. 4.B). As a result, the 2009/10 season was a below average rainfall season and the 2008/09 a slightly above average seasons. These differences in precipitation are likely to affect weed emergence between the two seasons.

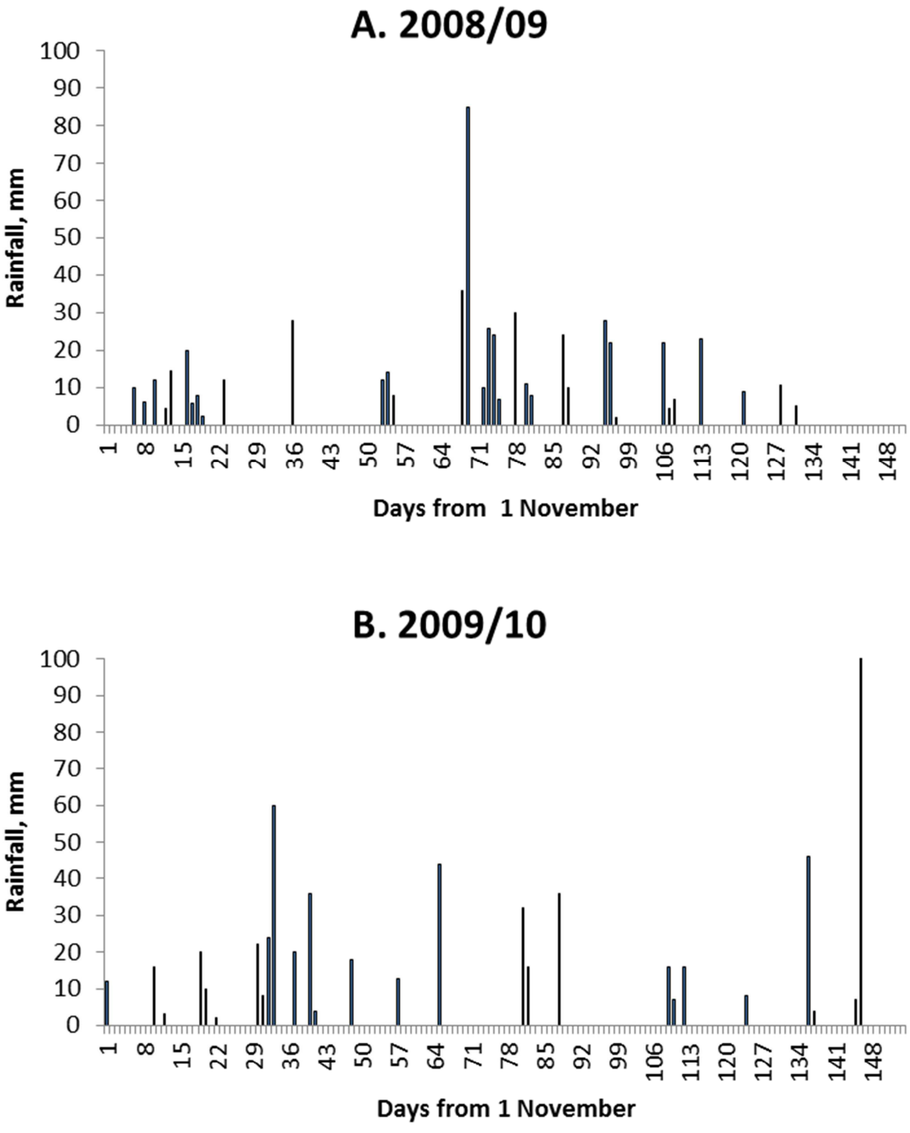

Fig. 4.1 Daily rainfall received between November and March at Matopos Research Station during the A. 2008/09 (561.1 mm) and B. 2009/10 (499.5 mm) cropping seasons

4.3.2 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 4.1 to 4.5. 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 season and *Boerhavia diffusa* and *Schkuria pinnata* in sorghum during the 2009/10 season (Fig. 4.2). 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 (Fig. 4.3). The maize mulch rate x weeding intensity interaction was significant ($P < 0.05$) for the density of *Ipomea plebia*, *S. pinnata* and *Setaria* spp. (Fig. 4.4) and annual monocots (Fig. 4.5) in sorghum grown during the 2009/10 season. These interactions are discussed below in detail under the respective subtitles.

4.3.3 Specific weed densities

Twenty-six weed species were identified in the cowpea phase in the first 13 weeks after planting (Table 4.1). Of these, twenty-four were also found among the twenty-five 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 *Malva 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 (Fig. 4.1) 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% by density of the weed community with annual monocots being the most abundant weed group in both crops (Table 4.1). 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.

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 variety used 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.

Table 4.1 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}	
		Cowpea	Sorghum
Annual dicots		87.3	123.7
	Acalypha crenata Hochst. Ex. A. Rich.	2.4	1.8
	Acanthospermum hispidum DC.	0.1	0.0
	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 prostrate Ait.	0.2	17.8
	Gnaphalium pensylvanicum Willd	6.3	-
	Ipomea plebia L.	-	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

A ‘-‘ shows species was absent from system.

4.3.3.1 Tillage effect

Tillage had no significant ($P > 0.05$) effect on the total weed density in both cowpea and sorghum crops (Table 4.2). 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 4.2). 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 4.2). 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 (Makanganise & Mabasa, 1999) and is likely to be more sensitive to light than large seeded weeds (Chauhan *et al*., 2006a) 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 MT systems especially for resource-poor farmers without access to pre-emergence herbicides.

Table 4.2 Effect of tillage main effect on cumulative density of weed species$^{\infty}$ found in cowpea (2008/09 season) and sorghum (2009/10 season) in the first 13 weeks after planting (WAP) at Matopos Research Station

Weed species	Weed density (m^{-2})							
	Cowpea				Sorghum			
	Tillage system				Tillage system			
	CONV	RT	PB	$LSD_{0.05}$	CONV	RT	PB	$LSD_{0.05}$
A. crenata	2.1	1.0	1.2	0.74	1.8	1.1	1.0	ns
C. tridens	4.0	2.4	2.3	0.83	3.8	3.0	2.9	ns
P. oleracea	1.4	2.0	1.9	0.41	2.8	2.6	2.6	ns
S. pinnata	1.0	1.4	1.4	ns	0.8	1.3	1.4	0.43
S. alba	-	-	-		1.5	1.0	0.8	0.39
Total density	14.5	13.7	13.3	ns	14.8	17.0	15.9	ns

$^{\infty}$ Weed species that had a significant response to treatment in at least one crop. Square root (x + 0.5) transformed data presented with value of 0.7 = 0 untransformed data. Abbreviations: CONV - Conventional mouldboard plough, RT - ripper tine; PB - Planting basin; LSD - Least significant difference; ns - not significantly different.

4.3.3.2 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. under sorghum (Table 4.3) 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 (Fig. 4.2). The association of *S. pinnata* with MT systems (Table 4.2) 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. oleracea*, *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 4.3). 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 4.3) and under ripper tine for *B. diffusa* (Fig 4.3). 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 4.3) and for some species with tillage system (Fig. 4.2) 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 4.2), 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 4.3) which is reported to be the most aggressive weed in Zimbabwe (Makanganise & 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.

Table 4.3 Effect of maize mulch rate main effect on cumulative density of weed species[∞] found in cowpea (2008/09 season) and sorghum (2009/10 season) in the first 13 WAP at Matopos Research Station

Weed species	Weed density (m^{-2})							
	Cowpea				Sorghum			
	Mulch rate t ha^{-1}				Mulch rate t ha^{-1}			
	0	4	8	LSD $_{(0.05)}$	0	4	8	LSD $_{(0.05)}$
G. pensylvanicum	1.8	2.7	2.7	0.50	-	-	-	
C. albida	1.2	1.7	2.1	0.57	0.9	0.8	0.9	ns
C. tridens	3.5	3.0	2.8	ns	3.9	3.2	2.7	0.70
B. diffusa	2.2	1.6	1.7	ns	1.7	1.3	1.7	0.38
E. indica	1.4	2.3	2.3	0.70	1.6	1.7	1.9	ns
E. prostrata	0.8	0.8	0.7	ns	4.8	3.6	2.9	1.00
L. martinicensis	4.2	5.7	4.8	ns	4.8	8.0	6.5	1.96
P. oleracea	1.9	1.7	1.6	ns	2.9	3.0	2.2	0.63
S. pinnata	0.9	1.1	1.8	0.63	0.7	1.0	1.8	0.32
Setaria spp.	8.6	9.1	9.0	ns	9.3	11.1	8.8	1.29
Annual dicot	8.3	10.1	9.0	1.23	10.5	11.5	10.2	ns
Annual monocot	9.4	10.2	10.1	ns	10.5	12.3	10.5	1.51
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	13.0b	14.6a	13.9a	0.89	15.7b	17.0a	15.0b	1.44

[∞] Weed species that had a significant response to treatment in at least one crop. Square root (x + 0.5) transformed data presented with value of 0.7 = 0 untransformed data. *Abbreviations*: LSD - least significant difference; ns - not significantly different.

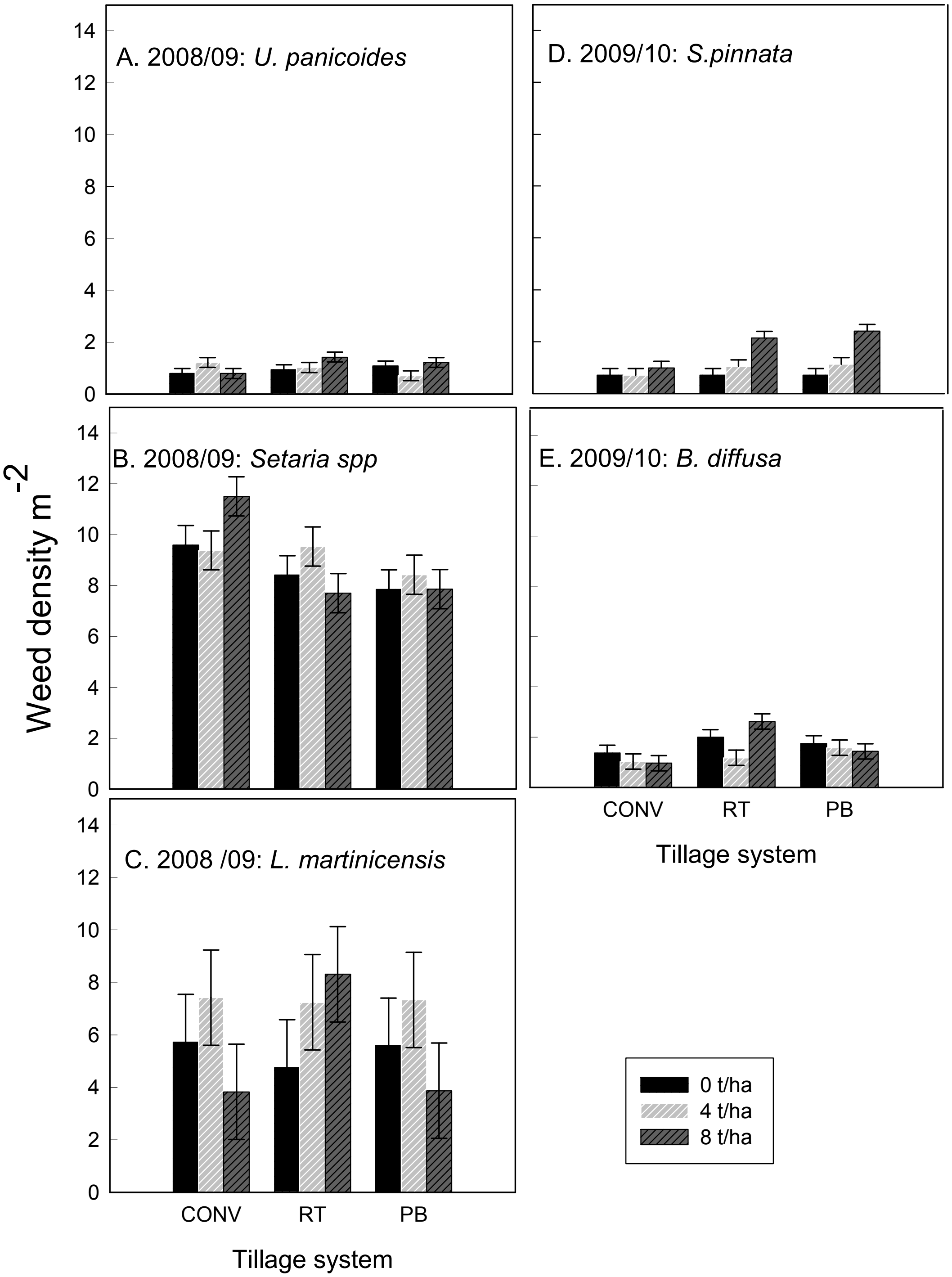

Fig 4.2 Tillage x maize mulch rate interaction on cumulative density in first 13 weeks of **A.** *U. panicoides*, **B.** *Setaria* spp. and **C.** *L. martinicensis* in cowpea (2008/09) and **D.** *S. pinnata* and **E.** *B. diffusa* in sorghum (2009/10) grown at Matopos Research Station. Narrow bars represent ± SED. Square root (x + 0.5) transformed data presented. *Abbreviations*: CONV - Conventional mouldboard plough, RT - ripper tine, PB - Planting basin; SED - Standard error of difference of the means

4.3.3.3 Intensity of hoe weeding effect

The high weeding intensity treatment 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 4.4). The higher density of annual weeds observed in the low weeding intensity treatment in sorghum may be a result of the 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 4.4). However for some species in both crops, the effect of weeding intensity was confounded within the significant ($P < 0.05$) tillage x weeding intensity interaction (Fig. 4.3). 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 (Fig 4.3 B, 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 (Fig. 4.3 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 x weeding intensity for *I. plebia*, *S. pinnata* and *Setaria* spp. in the sorghum crop (Fig. 4.4). The density *I. plebia* was reduced on mulching only in the low weeding intensity treatment (Fig. 4.4A). 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 (Fig. 4.4B). On the other hand, the high *Setaria* spp. density on maize mulching in sorghum (Table 4.3) was found under the high weeding intensity treatment (Fig. 4.4C). 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 (Fig. 4.5) 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 weed 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 & 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).

Table 4.4 Effect of intensity of hand-hoe weeding main effect on density of weed species[∞] found in the first 13 WAP in cowpea (2008/09 season) and sorghum (2009/10 season) crops at Matopos

Weed species	Weed density (m^{-2})							
	Cowpea				Sorghum			
	Weeding intensity				Weeding intensity			
	Low	High	LSD (0.05	% change	Low	High	LSD (0.05)	% change
A. repens	2.6	2.6	ns		4.2	2.8	0.99	33
A. mexicana	1.2	1.2	ns		0.9	0.7	0.09	22
B. pilosa	1.1	1.1	ns		2.6	1.7	0.57	35
C. benghalensis	3.2	2.6	ns		4.9	2.8	0.79	43
E. indica	1.5	1.2	ns		2.1	1.4	0.60	33
L. martinicensis	5.0	4.8	ns		8.3	4.6	1.29	45
S. oleracea	1.2	0.9	0.22	25	1.0	0.9	ns	
S. pinnata	1.2	1.2	ns		1.4	1.0	0.30	29
Setaria spp.	8.7	8.3	ns		12.a	7.0	1.17	45
U. panicoides	0.9	0.8	ns		2.9	2.0	0.63	31
Annual dicot	9.4	8.9	ns		12.8	8.7	0.99	32
Annual monocot	10.2	9.6	ns		14.1	8.1	1.21	43
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		19.4a	12.4b	1.23	36

[∞] Weed species that had a significant response to treatment in at least one crop. Square root (x + 0.5) transformed data presented with value of 0.7 = 0 untransformed data. *Abbreviations*: CONV - Conventional mouldboard plough, RT - ripper tine, PB - Planting basin; LSD - Least significant difference; ns - not significantly different.

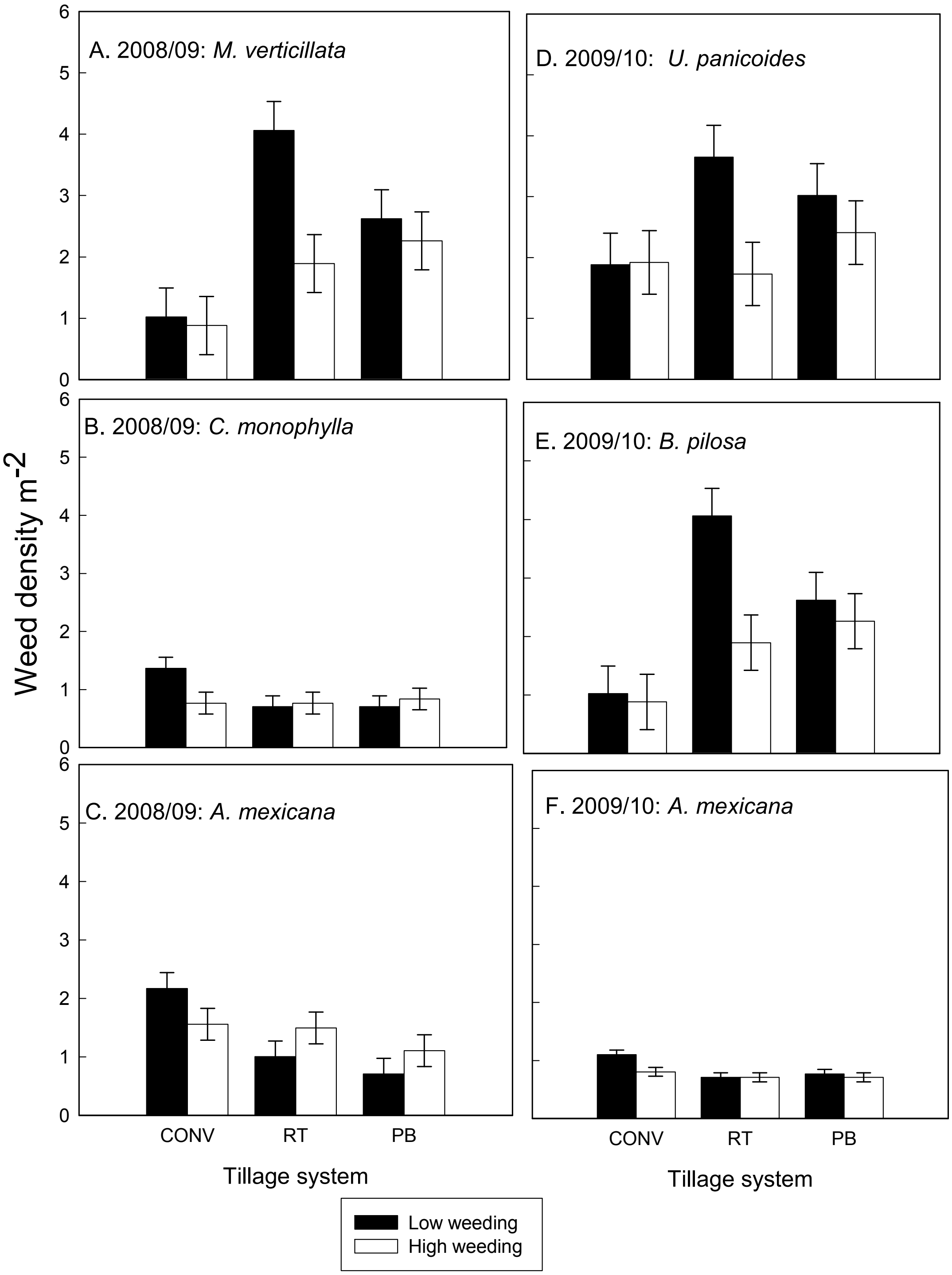

Fig 4.3 Tillage x weeding intensity interaction on cumulative density in first 13 weeks after planting of **A.** *M. verticillata*, **B.** C. *monophylla* and **C.** *A. Mexicana* in cowpea (2008/09) grown and **D.** *U. panacoides*, **E.** *B. pilosa* and **F.** *A. mexicana* in sorghum (2009/10) grown at Matopos Research Station. Narrow bars represent ± SED. Square root (x + 0.5) transformed data presented. *Abbreviations*: CONV - Conventional mouldboard plough, RT - ripper tine, PB - Planting basin; SED - Standard error of difference of the means

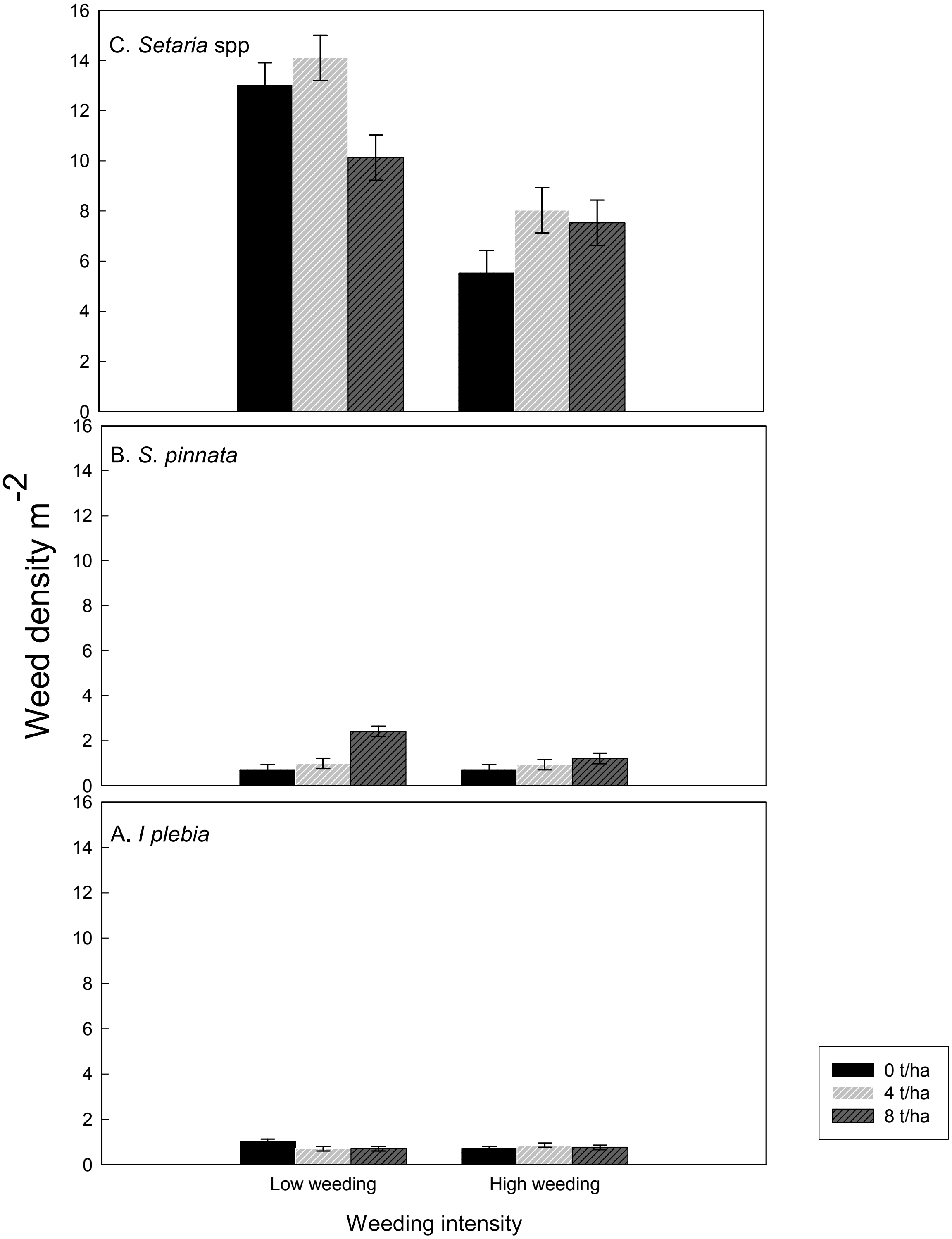

Fig 4.4 Maize mulch rate x weeding intensity interaction on cumulative density in first 13 weeks after planting of **A.** *I. plebia,* **B.** *S. pinnata* and **C.** *Setaria* spp. in sorghum grown at Matopos Research Station. Narrow bars represent ± SED. Square root (*x* + 0.5) transformed data presented. *Abbreviations:* SED -Standard error of difference of the means

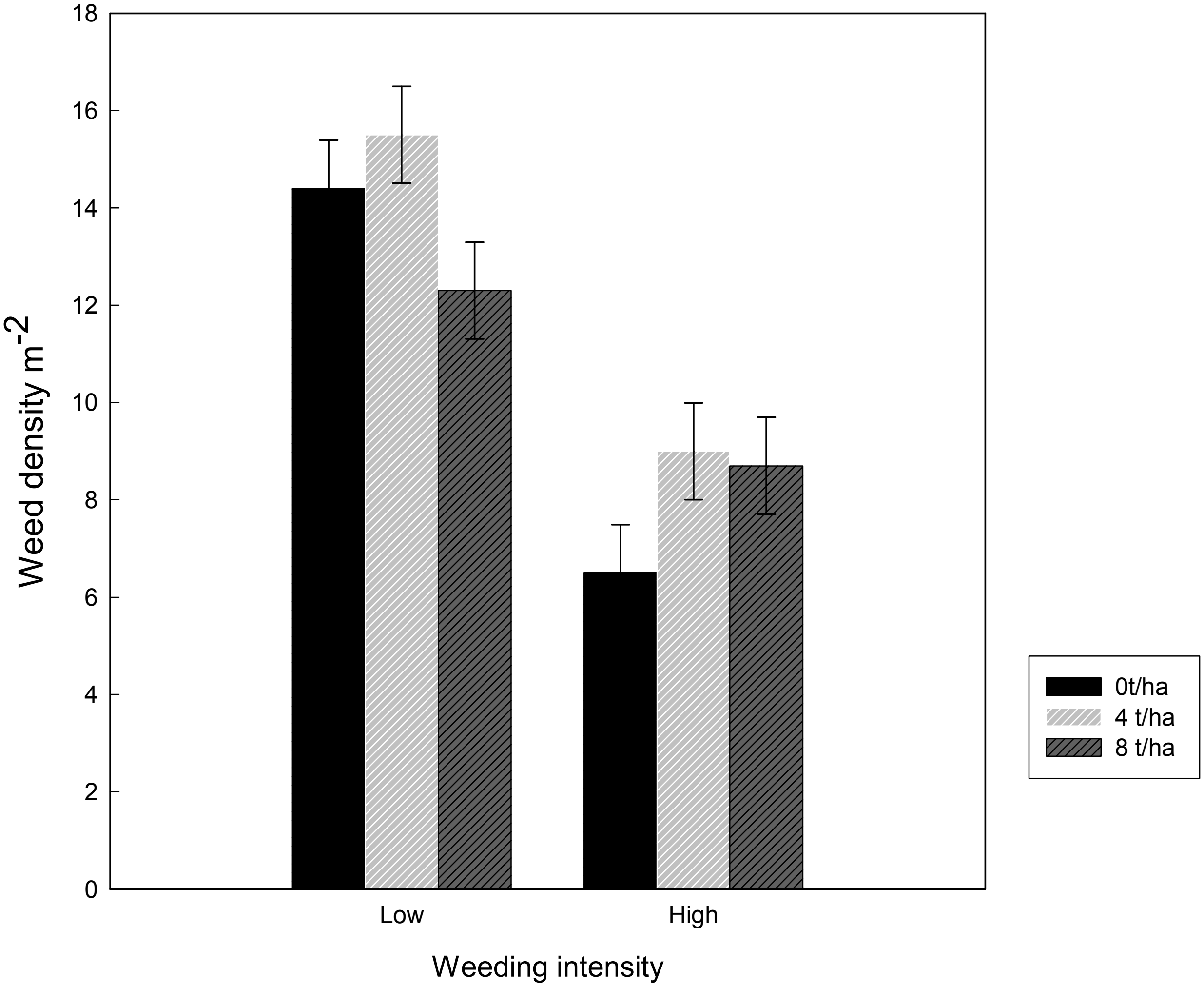

Fig. 4.5 Maize mulch rate x weeding intensity interaction on cumulative density in the first 13 weeks after planting of annual monocot species found in sorghum grown during the 2009/10 season at Matopos Research Station. Narrow bars represent ± SED. Square root (x + 0.5) transformed data presented. *Abbreviations:* SED - Standard error of difference of the means

4.3.4 Weed community diversity

Tillage had no significant effect on species richness, Shannon's diversity (H) and evenness (E) indices in both the cowpea and sorghum phases of the rotation (Table 4.5) which 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 4.3), the number of weed species in the communities did not vary in both crops (Table 4.5). 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 4.5). 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 4.3). 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 observed at the high weeding intensity across all the tillage systems in sorghum (Table 4.5). 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 this 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 4.5). 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.

Table 4.5 Richness (number of species per plot), diversity (Shannon's H' index) and evenness (Shannon's E index) for weed species present under different main 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
LSD $_{(0.05)}$	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
LSD $_{(0.05)}$	ns	ns	ns	ns	0.167	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
LSD $_{(0.05)}$	ns	ns	ns	1.16	ns	0.0367

Abbreviations: CONV - Conventional mouldboard plough, RT - ripper tine, PB - Planting basin; LSD - Least significant difference; ns - not significantly different.

4.4 CONCLUSION

This study provided new information that confirmed that CA can minimize the development of a weed community dominated by weed species associated with MT systems. The findings demonstrated that although *P. oleracea,* this species is unlikely to be a problem in CA when high maize residue rates of 8 t ha^{-1}. However, when maize residue retention is less than 8 t ha^{-1} *P.oleracea* may be a problem under CA. The weed *P. oleracea* can be difficult to control without herbicides as it also propagates by vegetative reproduction. This weed species was effectively controlled in this study through frequent hoe weeding. The weed species *S. pinnata* is likely to increase under CA as it was associated with MT systems and maize residue mulching. However, the weed was easily controlled when hoe weeding was done frequently. Maize mulching and use of a diversified crop rotation probably contributed to the lack of differences in weed community diversity between MT systems and CONV tillage. However, the intermediate maize residue rate of 4 t ha^{-1} had the least diverse weed community in sorghum probably as a result of the increased density under mulch of dominant weed species such as *Setaria* spp., *L. martinicensis* and *I. indica*. However, *e*arly and frequent hoe weeding effectively reduced weed density of these species by over 40%. This study demonstrated that the effect of mulching was dependent on tillage system, season and weed species such that generic conclusions on mulch effect on weeds were difficult to make. There was no evidence of a shift to more difficult to control weeds under CA in this study probably due to the effect of the different crops in the rotation and the differential effect of maize mulch on weed species emergence in the different seasons. There is a need to carry out a study of weed population dynamics in under smallholder farmer conditions and management CA. The effect of crop rotation on weed composition needs to be investigated using experiment where the different cropping systems including the monoculture are present in each season.