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Archives Of Phytopathology And Plant Protection
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gapp20

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Version of record first published: 01 Oct 2012.

To cite this article: R. Mandumbu, S.J. Twomlow, P. Jowah, N. Mashingaidze, L. Hove & C. Karavina (2012): Weed seed bank response to tillage and residue management in semi-arid Zimbabwe, Archives Of Phytopathology And Plant Protection, DOI:10.1080/03235408.2012.722842

To link to this article: http://dx.doi.org/10.1080/03235408.2012.722842

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Archives of Phytopathology and Plant Protection
i*First* article 2012, 1–12

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Weed seed bank response to tillage and residue management in semi-arid Zimbabwe

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(*Received 13 March 2012; final version received 10 April 2012*)

The influence of conservation agriculture (CA) on weed ecology has been a concern to many researchers across the world and is the focus of this study in southern Africa. An experiment to look at the impacts of various tillage systems with different levels of crop residue on maize (*Zea mays* L.) was established in 2004/2005 season. The experiment was carried out at the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), Matopos Research Station, Zimbabwe. Three main tillage systems were compared, ripping tillage (RT), planting basins (PB) and conventional tillage (CT), with three different crop residue levels: 0, 4 and 8 tons ha^{-1}. In 2007 soil samples were collected in the inter-row and in-row positions prior to tillage at 0–50 mm, 50–100 mm and 100–200 mm depths. The objective was to determine the effect of the treatment factors on weed seed bank species after three cropping cycles using the germination method. Nine major weed species were identified, with all the weeds unaffected by either tillage or mulching level. *Eleusine indica, Corchorus tridens* and *Setaria* species were the dominant weed species across all treatments. *Setaria* spp. was the dominant weed in the inter-row position of ripped plots. Although there was no significant individual treatment effect, there were significant ($p < 0.05$) interactions, with CT having reduced seed banks of *Setaria* spp. and *E. indica* compared to RT and PB. Percentage increases point to *E. indica* and *Setaria* spp. increasing under PB and RT compared to CT. *C. tridens* was significantly higher in PB compared to RT and CT in the 0–50 mm depth in the in-row position. This study probably coincided with the transition period in the weed bank succession process and needs to be repeated at a later date in the rotation. The majority of the weed species were not affected by any of the treatment combinations, a response attributed to plasticity of weeds to the tillage and residue level selection pressure.

Keywords: weed seed bank; mulch; tillage

Introduction

There is a growing worldwide concern about soil health, usage of fossil fuels and overall economics of field crop production. Conservation agriculture (CA) is being promoted globally as a farming system that can address many of those concerns and increase the overall economic productivity of mechanised agriculture (Norsworthy and

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ISSN 0323-5408 print/ISSN 1477-2906 online
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http://dx.doi.org/10.1080/03235408.2012.722842
http://www.tandfonline.com

Oleivera 2007; Hobbs et al. 2008; Sanyal et al. 2008). This is in direct contrast to sub Saharan Africa where CA is promoted as a potential solution to the production problems faced by small holder farming families in their quest to attain household food security (Haggblade and Tembo 2003; Mazvimavi and Twomlow 2009; Rockstrom et al. 2009; Twomlow et al. 2009). In this article, the terminology as defined by the United Nations' Food and Agriculture Organisation (FAO) CA task force for Zimbabwe has been adopted (Twomlow et al. 2008). Conservation is a broad term, which encompasses activities such as minimum and zero tillage, tractor powered, animal powered and manual methods, integrated soil and water management and includes conservation farming. It is generally defined as any tillage sequence that minimises soil and water loss and achieves at least 30% soil cover by crop residues.

The CA package, being promoted to Zimbabwe‘s vulnerable households includes hand dug planting basins (PB) and animal powered rip lines. Planting basins are structures that are dug from July through to October in the same positions annually: 15 cm (length) × 15 cm (width) × 15 cm (depth) dimensions (Mupangwa et al. 2006; Twomlow and Hove 2007). Planting basins benefit particularly poorer farmers with no access to draught power as they will not delay planting as they wait to borrow draught power from their neighbours (Mazvimavi and Twomlow 2009). Planting basins work on the principle that, rather than spreading nutrients and water uniformly over the field, it concentrates these in the basin to maximise yield for a given level of inputs (Hove et al. 2007). Rip lines are made from attachments fitted on the plough frame and were developed to open furrows for moisture capture and to break superficially compacted layers (Mapfumo et al. 2002). The rip lines go to a depth of 100–150 mm. Farmers using CA systems have achieved varying increases in yield compared to conventional tillage (CT): 15–75% (Twomlow and Hove 2007).

In addition to agronomic benefits, changes in tillage practices can also have a major influence on the relative abundance of weed species (Froud-Williams et al. 1981). Thierfelder and Wall (2007) found that PB and rip lines leave up to 80% of the soil surface undisturbed. The change in the level of soil disturbance and soil micro conditions might impact differently on different weed species. Tillage has been described as a filter (Smith 2006) or as a 'sieve' (Légére et al. 2005) that influences weed species in a given cropping system. The type of tillage offers a selection pressure on the weed population. The abundance of a species has more to do with the abundance of habitable sites and genetic and phenotypic plasticity that allow a wide range of sites to be occupied (Harper 1977). Weed species with the best adapted genotypes assume numerical dominance and those with traits that make them susceptible to a given filter or set of filters are less likely to be present in a given weed community. The uptake of CA practices has been shown to lead to shifts in the weed communities (Tørresen et al. 2003). Other authors have reported an increase in annual grasses, perennial weeds and wind dispersed species. At the same time, examples are provided in literature where weed communities showed no consistent response to CA (Derksen et al. 1993). However, only limited studies have been undertaken on the impacts of tillage on the weed ecology of the smallholder farming systems of southern Africa (e.g. Shumba et al. 1992; Mabasa et al. 1998).

According to Wruckle and Arnold (1985), annual grass populations usually increase in no tillage systems concomitant with a decrease in populations of dicotyledonous weeds.

Froud-Williams et al. (1981) predicted that annual and perennial grasses, perennial dicot species, wind disseminated species and volunteer crop would increase and annual dicot species would decrease in association with reduced tillage systems. Cardina et al. (2002) found greater weed seed bank density in no-till compared to till experiments. Moonen and Barberi (2004) found five fold higher seed bank density in reduced tillage systems compared to till. Studies by Barberi and Lo Cascio (2001) found the highest weed seedling density in no-tillage plots compared to chisel and mouldboard ploughing. Oryokot and Swanton (1997) found that *Amaranthus* spp. seedling density was much higher in no-till environments compared to tilled environments. It was confirmed by Barberi and Lo Cascio (2001) who found higher *Amaranthus* spp. and summer grasses in no-till compared to till.

Despite widespread promotion of CA in Zimbabwe's vulnerable rural communities (Twomlow et al. 2008), information is not available on which weed species are expected to become a problem after several years. The main objective of this study was to determine how individual weed species respond to the pressure of tillage and residues in the seed bank after three years.

Materials and methods

Experimental site

The trial was conducted at Matopos Research Station (MRS). The station is located about 30 km south of the city of Bulawayo. Bulawayo is considered to be a representative of climatic conditions found in south west Zimbabwe and much of Botswana, southern Mozambique and Zambia (Twomlow et al. 2006). The experimental site (28° 30.92′ E, 20° 23.32′ S) is 1344 m above sea level. This region is characterized by semi-arid climatic conditions with annual rainfall ranging between 450 mm to 650 mm. Rainfall season is unimodal and begins in November/December and ends in March/April (Mupangwa et al. 2007). The long-term rainfall average for the site for the last 35 years was 570 mm.

The soil at the site is a clay loam and is classified as either shallow Siallitic soil (4E.1) according to the Zimbabwean system of classification or a Chromic-leptic Cambisol according to FAO system (Moyo 2001). The experimental plots from which the samples were taken have 41% clay content with the internal drainage indicating saturation for short periods during the rainy season and external drainage characterized by slow runoff (Moyo 2001).

Experimental design

The trial from which the samples were taken was a factorial experiment with two factors laid out as a split plot design with tillage as the main plot factor and residue level as the subplot factor with three replicates. Three main plot tillage systems were ripping; CT and PB and the three subplot factor residue levels were 0, 4 and 8 tons ha^{-1}. The plots measured 8 m $\times$ 6 m and were established in September 2004, three seasons prior to sampling. Maize residue from the previous seasons was applied. Additional residues were removed from adjacent fields at harvests and applied to the experimental plots just before land preparation according to the experimental design.

Cropping history of the plots

The trial was established in the 2004/2005 cropping season. Previous crops planted in the research plots are as shown in Table 1.

Table 1. Crops grown in the experimental plots for the 2004/2005–2007/2008 seasons.

Season	Crop
2004/05	Maize
2005/06	Cowpeas
2006/07	Sorghum
2007/08	Maize

Weed control in the plots was primarily hoe weeding with glyphosate being used to control *Cynodon dactylon* L. patches within the plots.

Planting basins were dug using hand hoes at a spacing of 0.6 m × 0.9 m with each basin having dimensions of 0.15 m × 0.15 m × 0.15 m (length × width × depth). Ripping to a depth of 150 mm was achieved using a Zimplough^{TM} ripper tine attached to the beam of an ox-drawn mouldboard plough. For mouldboard ploughing, a donkey drawn VS200^{TM} mouldboard plough was used to plough the conventionally tilled plots to a depth of between 0.15 and 0.2 m depending on soil moisture content at tillage.

Weed seed bank studies

Soil seed bank sampling was done in November 2007 before planting, three seasons after the trials had been established. Soil cores were taken using 0.04 m diameter augers to a depth of 0.2 m. Six positions were sampled from the four row net plot using the diagonal method. In rip lines, three samples were taken from the inter-row area and the other three from the intra-row area within the rip line. In the PB three samples were collected from within the basin and the other three from the inter-row area which had no basins. In the CT, three samples were collected along the previous plant row and the other three in the inter-row area. The soil samples from the augers were excavated to separate the soil into 0–5 cm, 5–10 cm and 10–20 cm depths. The samples were stored in a cold room at 4°C in the dark until germination, which started on 4 February 2008.

The dimensions of the plastic pots used for germination of the weed seeds in the soil samples were 11.5 cm base diameter, 15 cm top diameter and 12 cm height (Kord Products 6'' AZ155MM). Coarse river sand was sterilized in an oven at 120°C for 24 hours to kill weed seeds. A total of 162 pots were filled up to a height of 7 cm with sterilized river sand to form sand bed on top of which the soil samples were spread. The pots had drainage holes at the base to allow free water drainage. Two hundred gram samples were spread over the sand bed on the plastic pots and placed in a greenhouse where temperature was not controlled. The pots were randomly arranged in the greenhouse and the positions were changed randomly every week.

Each pot was watered with 300 ml of water daily to maintain optimum moisture in the pots as the conditions in the greenhouse were hot. Emerged weed seedlings were identified, counted and removed daily. Seedlings too small to be identified were marked with coded sticks and allowed to grow until their identity could be ensured.

The plastic pots were maintained within the greenhouse for three months, rested for one month and put in the greenhouse for another three months. The resting was done by putting the pots into the cold room where temperature was maintained at

4°C. The soil samples in the plastic pots were stirred midway through each growing period to bring weed seeds to the top and enhance their germination.

Data analysis

Weed counts were subjected to analysis of variance (ANOVA) using Genstat (2008) version 10. Where treatments means were statistically significantly different, they were separated using least significant difference (LSD) at the 5% significance level.

Results

Number of species recorded

A total of 14 weed species were recorded in the seed bank taken from the experimental plots over the 24-week assessment period. All the weed species were annuals with the exception of *Alternanthera repens*. Due to high similarity of *Setaria pumila* (Poir.) Roem. & Schult. and *Setaria verticillata* (L.) P. Beauv., they could not be identified to species level and thus were recorded at genus level as *Setaria* spp. The dominant weed species that were present in the seed bank included foxtail (*Setaria* spp.); *A. repens* (L.) Kuntze; smooth pigweed (*Amaranthus hybridus* L.); wandering Jew (*Commelina benghalensis* L.; jute (*Corchorus tridens* L.); stinkblaar (*Datura stramonium* L.); rapoko grass (*Eleusine indica* (L.) Gaertn.; *Euphorbia prostrata* Ait.; purslane (*Portulaca oleracea* L.); Bobbin weed (*Leucas martinicensis* (Jacq:) R. BR.; *Boerhvia repens* (L.); *Ricardia scabra* (L.); *Sonchus oleracea* (L.) and garden urochloa (*Urochloa panicoides* (Beauv.)). The first nine weeds accounted for 97% of the total weed seedlings that emerged in the 0–200 mm layer of the seed bank during the incubation period regardless of experimental treatment.

Effect of tillage systems on weed species

Table 2 summarizes the total number of weeds seedlings by species that germinated from 200 mm samples for the three tillage treatments. Even after three years of treatment application, there were no overall statistical effects of tillage on weed

Table 2. Average number of different weeds species per 200 mm sampling depth.

	Tillage					
Weed Species	Conventional	Ripping	Basins	*p* value	SED	$LSD_{0.05}$
A. repens	0.61	0.39	0.63	0.707	0.22	ns
A. hybridus	2.79	2.92	2.51	0.966	3.10	ns
C. benghalensis	2.47	4.59	3.39	0.656	4.40	ns
C. tridens	3.62	1.55	2.98	0.601	3.94	ns
D. stramonium	0.97	0.71	1.21	0.675	1.07	ns
E. indica	3.50	7.14	5.44	0.223	1.42	ns
E. prostrata	3.20	4.85	5.48	0.582	4.22	ns
P. oleracea	9.52	6.51	10.20	0.383	5.02	ns
Setaria spp.	21.9	27.9	26.20	0.242	6.08	ns
Total weeds	5.07	6.93	6.76	0.177	0.62	ns

SED denotes standard error of the difference; LSD denotes least significant difference; ns means not significant.

number. However, it is worth noting that after three seasons there was an overall trend of increasing weed numbers from conventionally tilled plots to the reduced tilled plots.

Despite the lack of any statistically significant impact of tillage on the proportions of *C. tridens*, it is worth noting the declining trend observed. In this fourth cropping cycle the *C. tridens* accounted for 57% of the total weed seed bank under CT system, compared to 17% under mulch ripping and PB. Although *E. indica* showed similar statistical results to *C. tridens*, the observed responses were in direct contrast with the reduced tillage plots showing an increasing trend from CT to ripping and basins.

Effect of residue levels on weed species

Despite the fact that there were no statistical impacts of residues on weed numbers (Table 3) in the top 200 mm of the soil profile, it is worth noting that the trend *A. hybridus, E. indica, E. prostrata* and *P. oleracea* increase with increasing residues irrespective of tillage system.

Interactions between and among factors on weed species

A significant interaction ($p = 0.02$) of tillage, depth and core position on *C. tridens* (Table 4) indicates that *C. tridens* was higher in the basins in the 0–50 mm sampling depth in the in-row positions compared to inter-row positions under the ripper, although it was not different from CT.

There was a significant interaction ($p = 0.013$) of tillage and core position in the *Setaria* spp. numbers (Table 5).

The results indicated that *Setaria* spp. numbers in the inter-row sampling positions under ripping were higher compared to both conventional and PB. Basins had higher numbers of *Setaria* spp. in the in-row positions compared to CT. The results indicate that in the in-row positions the basins had 55% higher *Setaria* spp. compared to CT. In the inter-row position ripping had 56% more *Setaria* spp. compared to CT and 67% more compared to basins.

Table 3. Effect of residue levels on weed species numbers per 200 mm sampling depth.

Weed species	Residue level (tonsha^{-1}) 0	4	8	*p* value	SED	$LSD_{0.05}$
A. repens	0.44	0.41	0.78	0.134	0.132	ns
A. hybridus	1.55	3.25	3.39	0.241	1.14	ns
C. benghalensis	3.46	4.70	2.29	0.278	1.42	ns
C. tridens	3.26	1.58	3.33	0.266	1.145	ns
D. stramonium	1.47	0.71	0.71	0.226	0.48	ns
E. indica	5.10	4.82	6.16	0.746	1.81	ns
E. prostrata	3.57	5.72	4.22	0.456	1.70	ns
P. oleracea	5.75	10.38	10.13	0.239	2.90	ns
Setaria spp.	26.3	28.80	20.70	0.357	5.54	ns
Total weeds	5.74	7.3	5.72	0.483	1.027	ns

SED denotes standard error of the difference, LSD denotes least significant difference; ns denotes not significant.

Table 4. Effects of tillage, sampling depth and sampling position on mean number of *Corchorus tridens* seedlings that germinated.

	0–50 mm		50–100 mm		100–200 mm	
Tillage	In-row	Inter-row	In-row	Inter-row	In-row	Inter-row
Conventional	2.46	4.21	4.21	5.96	2.46	2.46
Ripper	0.53	2.46	0.71	2.46	2.46	0.71
Basin	7.71	0.71	4.21	0.71	0.36	4.21
p value	0.02	ns	ns	ns	ns	ns
SED	2.91					
$LSD_{0.05}$	5.79	–	–	–	–	–

SED denotes standard error of the difference; LSD denotes least significant difference; ns means not significant.

Table 5. Effects of sampling position and tillage system on *Setaria* spp. numbers in the 200 mm sampling depth.

Tillage	In-row		Inter-row
Conventional	19.7		24.1
Planting basins	29.2		23.2
Ripper	22.4		33.3
p value		0.013	
SED		4.15	
$LSD_{0.05}$		8.19	

SED denotes standard error of the difference, LSD denotes least significant difference; ns means not significant.

Effect of treatment factors on totals weeds

Total weed numbers showed the following order: ripping > basins > conventional. Seed bank size given as total weeds in the whole (0–200 mm) layer did not significantly differ among tillage systems (Table 2). The basins had higher total number of weeds (Table 6) in the in-row position compared to other tillage systems. The ripper had a significantly higher weed totals compared to CT and PB.

Table 6. Effect of tillage and sampling position on total weed numbers per 200 mm sampling depth.

Tillage	In-row		Inter-row
Conventional	4.63		5.52
Ripping	4.78		9.07
Basin	7.33		6.19
p value		0.019	
SED		0.916	
$LSD_{0.05}$		1.79	

SED denotes standard error of the difference; LSD denotes least significant difference; ns means not significant.

There was, however, a significant interaction ($p = 0.013$) of tillage system, depth and sampling position on weed seed bank size (Table 7). The results indicate that the in-row position in basins had significantly higher seed bank size than the other two

Table 7. Effects of sampling depth, position and tillage on mean total number weed seeds.

Tillage	In-row			Inter-row		
	0–50 mm	50–100 mm	100–200 mm	0–50 mm	50–100 mm	100–200 mm
Conventional	6.44	4.11	3.33	6.44	5.78	4.33
Ripper	4.0	5.78	4.56	13.11	9.33	4.78
Basins	11.89	6.00	4.11	5.89	7.22	5.44
p value	0.013	ns	ns	0.013	ns	ns
SED	1.636					
$LSD_{0.05}$	3.26	–	–	3.26	–	–

SED denotes standard error of the difference; LSD denotes least significant difference; ns means not significant.

tillage systems. In the inter-row positions, the ripper had significantly higher weed seed bank size compared to the other tillage systems.

Discussion

Three other agronomic practices, in addition to the tillage systems investigated may have contributed to the weed seed bank response trends observed in this study. First, the effect of the previous rotations on specific weed species was not measured, so its contribution to the observed trend is unknown. Second, continuous weeding, which included winter weeding to prevent late seeding, as recommended by the Zimbabwe Conservation Agriculture Task Force could have impacted on the weed seed banks. Finally, this study was carried out in plots where reduced tillage had been in use for three successive seasons, which may have been too short a period to register any changes due to succession. Moonen and Barberi (2004) found significant differences in seed bank response to different tillage systems after seven years while Barberi and Lo Cascio (2001) and Thomas et al. (2004) did so after 12 years.

Weed response to tillage was expressed in terms of biological traits of a particular species that are generic and were used to explain responses to changes in tillage practices. This was previously used by Thomas et al. (2004) as they had found that there were exceptions to simple classifications and predicted responses of weeds to changes in tillage systems. Genotypic and phenotypic plasticity and ecological adaptations by specific weed species may explain some of the responses of specific species when subjected to selection pressure. Weeds may possess adaptive traits that make them to survive the effects of the treatment factors.

Effect of tillage and residues on weeds

Fourteen weed species were recorded in the seed bank. This number does not come close to the range of 19–79 found in more temperate regions with different crop management systems (Cardina et al. 2002; Ivany and Carter 2006). All weed species found were annuals except one. *Cynodon dactylon* L. was seen in patches in the field during sampling but it could not be picked by sampling as it reproduces mainly vegetatively in the tropics (Guglielmini and Satorre 2004).

The lack of treatment effects of tillage on *Setaria* spp. is in contrast to the findings of Buhler and Mester (1991) and Barberi et al. (2001) but is supported by Miller and Nalewaja (1985) and Derksen et al. (1993) who found no association of

Setaria spp. with any tillage system. However, the significant interaction ($p = 0.013$) which showed increased *Setaria* spp. numbers in the inter-row position under the ripper (Table 4) agree with the studies by Barberi et al. (2001). Under the ripper, the inter-row position is undisturbed during tillage and *Setaria* spp. has small seeds which can establish on firm, undisturbed soil surfaces. The percentage increases of 27% and 19% from CT to ripping and planting basin may indicate that succession is in progress towards increased numbers in minimum tillage plots.

In this study *E. indica* was not affected by treatment factors. This does not agree with the findings of Mester and Buhler (1991), Thomas et al. (2004) and Chauhan and Johnson (2008) who report increases in rapoko grass with reduction in level of soil disturbance. The percentage increases of 104% and 55% from CT to ripper and PB may be supporting the notion of increased rapoko grass in CA systems. The reason for non-correspondence of these results with the results of previous researchers may be the age of the experiment which was three years so the studies could have coincided with a transition stage in succession.

Corchorus tridens was affected neither by tillage nor residue levels three years after establishment of the experiment. However, there was decrease of 57% and 17% from CT to ripper and PB, respectively. This indicates that *C. tridens* is more adapted to CT as it is decreasing with a decrease in the level of soil disturbance. Increased jute numbers in the in-row position in the PB could be due to the combined effect of the basin making process and the water harvesting process that washes *C. tridens* seeds into the basin. Chauhan and Johnson (2008b) showed that *C. tridens* is not photoblastic so it can germinate even when buried under residues and in the soil.

Amaranthus hybridus was not affected by tillage and residue levels (Tables 3 and 4). These results concur with the findings of Vencill and Banks (1994); Tuesca et al. (2001) and Thomas et al. (2004), who reported independence of *A. hybridus* to tillage. The weed has a high degree of ecological and phenotypic plasticity which confers pre-adaptation to a wide range of habitats and growing conditions. This could have assisted the weed to resist the selection pressure from tillage and residues. According to Duke (1985), the weed can germinate from shallow and deeper depths and that can ensure uniform germination from CT and from the ripper and PB.

Tillage and residues did not have any impact on *C. benghalensis* (Tables 3 and 4). This could be because the weed is very versatile. According to Matsuo et al. (2004), the wandering jew can germinate at 100 mm depth and does not require light to germinate. This implies that the presence of residues and deep burials which alter light quality and quantity cannot affect the germination of wandering jew. Tillage breaks the weed into pieces and that perpetuates the weed problem as it propagates by fragmentation.

All the other weed species were not affected by treatment factors and did not show any persistent percent responses to treatment. This was attributed to various adaptability mechanisms. It can be predicted that these weeds could increase across all tillage systems and seemed independent of the imposed selection pressure.

Effect of treatment factors on total weeds

There was no difference in the seed bank size among the different tillage systems (Table 2). This corroborates the findings of Barberi and Lo Cascio (2001) who observed no differences in the sizes of the weed seed bank between ploughed and unploughed fields. This could be attributed to weed management recommendation in the CA protocol for the tropics that stipulates that no weed seed should be allowed to shed. It is likely that the weed seed bank is declining due to decay, predation and other natural processes across the minimum tillage treatments. The weeds that were brought by wind quickly germinated due to higher moisture and were weeded out. The results, however, indicate that ripping has bigger seed bank size in the inter-row position on the 0–50 mm (Table 7). The seed bank builds up if the seed input rate is higher than the depletion rate. According to Moonen and Barberi (2004), seed bank depletion is stimulated by soil cultivation, seed mortality and predation. Under CT, seeds are distributed more evenly with depth than in ripping tillage in the 0–50 mm sampling depth (Table 7). Basins have a higher seed bank size in the 0–50 mm depth compared to the ripper and CT (Table 7). This can be attributed to the water harvesting process in the basin which can carry weed seeds into the basin as water is harvested into the basin.

Conclusion

This study suggests no statistical significant individual impacts of tillage and residue levels on weed numbers after three years in the top 200 mm of the profile. However, significant interactions point to the fact that *Setaria* spp. and *E. indica* are expected to become a problem after several years in basins and under the ripper. *C. tridens* can become a problem in PB. Total weeds were more in PB compared to the ripper and CT after three years of tillage introductions. CA adopters in the semi-arid areas of southern Africa should prepare to deal with *Setaria* spp., *E. indica* and *C tridens*. Further work is required on the same trial to determine any changes in trend as succession progresses.

Acknowledgements

The authors are grateful to the United Kingdom's Department for International Development (DFID) for funding the project under the Protracted Relief Program1, The International Crop Research Institute for the semi Arid tropics (ICRISAT) for hosting the project and the University of Zimbabwe where the senior author was studying for his MSc degree. The material presented in this paper has been extracted from a thesis submitted for the award of MSc degree.

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