Weed community responses to soil type during transition to no-till practice on smallholder farms in Zimbabwe

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Abstract

Understanding drivers of weed density and diversity is essential for the development of weed management strategies. Here, we compared temporal changes in weed density and diversity under no-till (NT) and conventional (CONV) tillage systems in cotton–maize rotations on loam, clay loam and sandy loam soils immediately after transition to NT in Kadoma, Zimbabwe. The effect of tillage system on weed density varied through the growth season and was dependent upon soil type and species composition of the weed community. Although weed responses to tillage system varied amongst species, we identified general trend effects on weed density on specific soils. At 3 weeks after crop emergence (WACE), weed density on loam soils was 76% and 96% higher in NT than in CONV during the 2009/2010 and 2010/2011 seasons, respectively, and on clay loam soils it was 37% and 33% higher in NT than CONV, respectively. Weed densities in NT and CONV were similar across all soil types at 6 WACE during the 2009/2010 and 2010/2011 seasons and at 9 WACE in 2009/2010. Tillage system did not affect weed density during the growth season on sandy loam soils. Weed diversity (Shannon index) was at least 75% higher in NT than CONV on loam and clay loam soils at 3 WACE during both seasons. It is likely these increases in weed densities following conversion to NT will exacerbate already prevalent weed management problems in the smallholder sector. Earlier weeding is recommended to suppress weed emergence and reduce likely associated crop yield losses.

Keywords: cotton–maize rotation; smallholder farms; soil type; tillage system; weed density; weed diversity

1 INTRODUCTION

Since 2004, the United Nations Food and Agriculture Organization (FAO) have, with support from governmental and non-governmental organisations, made a concerted effort to promote no-till (NT) tillage systems amongst smallholder farmers in sub-Saharan African countries, including Zimbabwe (Nyamangara *et al*., 2014). The promotion of NT is meant to address the many challenges farmers face in crop production, including farming on unproductive soils, accelerated land degradation and high input costs of inputs such as labour and the associated costs (Mtambanengwe *et al*., 2015). To date, the adoption rate of NT is low amongst smallholder farmers in Zimbabwe. This is partly because these Zimbabwean farmers are concerned about increased weed pressure following conversion from conventional (CONV) tillage systems to the NT system. Such concerns are substantiated by reports, of increased weed density in NT systems, relative to that of CONV, from Mozambique, Zambia, Lesotho and Malawi (Nicole and Thierfelder, 2017).

Increases in weed density following the adoption of NT will exacerbate weed management problems on smallholder farms, which generally rely on hand hoeing and family labour. The availability of labour and animal draught power influences the timing of cultivation, sowing and weed control. These factors, combined with environmental conditions, influence the rate of growth and the subsequent management of weeds. For example, during periods of high rainfall, when the weeds develop very rapidly and extremely densely, they contribute to low crop yields. Their management is thus a significant crop production constraint in the smallholder sector (Muoni and Mhlanga, 2014), therefore making hand hoeing inefficient (Mafongoya *et al*., 2016).

The reports from the literature are inconsistent; in addition to variations in weed density, NT can influence the dynamics of the weed community. Whilst Mhlanga *et al*. (2015) report that under annual rotations of maize, NT increased the weed diversity with different cover crops, (Mashingaidze *et al*., 2012) on the other hand, found no differences in weed density and community composition between NT and CONV tillage, under rotations of sorghum–cowpea. Similarly, no significant differences in weed densities between NT and CONV were observed in winter wheat crops (Bàrberi *et al*., 2001). Mohler (1993) notes that the findings of various studies of weed responses to tillage are influenced by the interactions between diverse variables, such as weather, duration of the study and the long-term history of the field. Fried *et al*. (2008) found weed communities on clay soils were different from those growing on sandy soils. The diversity of findings of the effects of tillage on weed communities is a reflection of the complex interactions between cropping systems and weed dynamics and, as indicated above that other factors, such as soil characteristics, also play a role (Vasileiadis *et al*., 2012). Previous research has furthermore determined that the distribution and abundance of weeds across the landscape could also be indicative of variations in soil properties (Fried *et al*., 2008; Abbasvand *et al*., 2014). Therefore, NT effects on weeds are likely to be determined by soil type.

The main objective of this study was to compare weed density, diversity, and the timing of weed emergence in NT and CONV systems in different soil types on smallholder farms in Zimbabwe. As discussed above, the combined findings of several previous studies suggest that NT effects on weed communities are context-specific (Bàrberi *et al*., 2001; Fried *et al*., 2008; Mashingaidze *et al*., 2012; Mhlanga *et al*., 2015). Smallholder farmers in Zimbabwe have limited resources for managing unexpected changes in weed infestations, making it essential to understand how NT affects weed communities in smallholders' fields.

2 MATERIALS AND METHODS

2.1 Site description

During the 2009/2010 and 2010/2011 growing seasons, experiments were conducted near the town of Kadoma, Zimbabwe (−18°0.467010 E, 29°0.616970 S). Soils which vary from silty clay loams to clays classified as Chromic Luvisols (FAO, 1974) support the two major crops grown in the area: cotton (*Gossypium hirsutum* L.) and maize (*Zea mays* L.). Three separate locations in the same geographical area were selected within a mosaic of 5 040 ha of arable and 2 100 ha of grazed areas. Within each location, six farms and one field per farm were selected. The six farms from each of the three localities represented either loam, sandy loam or clay loam (Table 1). All the selected fields were under CONV tillage for an average of 20 years before the study. All selected fields were under maize–cotton rotations before and during the study period. A rain gauge was installed at each site before commencement of the study, and rainfall data were collected every day. Daily temperature data were collected from a weather station in Kadoma.

Table 1. Soil texture characteristics at study sites

Farm	Texture			Textural class
	Sand	Silt	Clay	
1	48.1	38.1	13.8	Loam
2	31.6	48.4	20.0	
3	41.2	46.3	12.5	
4	36.9	40.6	22.5	
5	49.5	30.5	20.0	
6	37.2	40.9	21.9	
7	55.0	27.0	18.0	Sandy loam
8	54.1	27.9	18.0	
9	55.5	27.6	16.9	
10	57.7	30.4	11.9	
11	58.8	29.3	11.9	
12	55.4	27.6	17.0	
13	27.8	37.8	34.4	Clay loam
14	41.0	29.0	30.0	
15	41.7	28.3	30.0	
16	35.7	36.8	27.5	
17	30.0	31.0	39.0	
18	22.5	44.5	33.0	

2.2 Field procedures

At each site, plots were positioned side-by-side using a paired comparison design. Each plot, representing either the NT or CONV system, was 6 × 5.4 m. The paired plots were laid out in a randomised complete block design, replicated three times at each farm. The experiments were repeated in the same plots during the second year of the study. CONV tillage plots were ploughed using an ox-drawn mouldboard plough twice during the year, in winter and spring. The plough depth was up to 0.23 m. Sowing furrows in CONV were also made with the ox-drawn mouldboard plough, to a depth of 0.15 m. The creation of sowing furrows eliminated weeds before planting. Glyphosate (Roundup® 360, Monsanto Company, St Louis, MO, USA) was applied at a rate of 360 g a.i./L one week before sowing in NT plots to control all weeds before planting. The spray volume was 200 ℓ/ha, and the spray pressure was 250 kPa. The herbicide was applied with a 15 ℓ knapsack sprayer through flat fan nozzles that evenly covered a swath width of 0.3 m. The NT plots were only disturbed when pits were dug to create planting basins measuring 0.15 m × 0.15 m × 0.15 m, in which seeds were sown.

A medium-maturity cotton variety was sown on 10 December 2009 in both NT and CONV systems. A maize hybrid, which matured in 135 days after sowing, was sown on 7 December 2010. Cotton and maize were both seeded with 0.3 m in-row spacing and 0.9 m inter-row spacing. Three seeds were sown per hole and were thinned to one plant per hole at two weeks after crop emergence (WACE) for both crops. All plots were weeded with hand hoes at 3, 6 and 9 WACE. Fertiliser for maize (7% N: 14% P_2O_5:7% K_2O + 8S) and cotton (5% N: 17% P_2O_5:8% K_2O + 0.1% B) was applied at a rate of 200 kg/ha at sowing. Both cotton and maize crops were top-dressed with ammonium nitrate fertiliser (NH_4NO_3-) at a rate of 100 kg/ha per application at 5 and 9 WACE.

2.3 Soil sampling and analysis

Five soil samples from equally spaced positions were taken along a transect that ran diagonally through each of the 18 fields. A soil sampler measuring 0.7 m in diameter and 0.20 m deep was used to collect the soils from five positions. The five samples from each field were combined to make one composite sample for analysis. The soil samples were air-dried and passed through a 2-mm sieve to remove plant debris and coarse fragments. Clay and silt contents were determined by the hydrometer method with NaP_2O_2 as the dispersing agent (Gee and Bauder, 1986). The sand fraction was determined by wet sieving.

2.4 Weed assessment and data analysis

On average, the maize and cotton crops emerged seven days after sowing. In each plot, weeds that had emerged at 3, 6 and 9 WACE were counted at species level within three 0.50 m^2 quadrats that were positioned using the random-pair technique during each season (Nkoa *et al*., 2015). The positions of the quadrats were changed the following season. All weeds were pulled out from the quadrats after the counting process, meaning that the values at 6 and 9 WACE were newly emerged weeds since the last recording and were not accumulated weeds that had emerged since sowing. Weeds outside of the quadrats, but within study plots, were removed with hand hoeing soon after weed counts. The mean of the three quadrats was calculated to characterise the weed density of each plot. The pulling of weeds might have disturbed the soil and brought weed seeds to the soil surface, where conditions were conducive to germination, with enough light and moisture. There were no weed counts at 9 WACE during the 2010/2011 season because there was no precipitation in February, which prohibited weed emergence after weeding at 6 WACE.

The weed species diversity, which demonstrates the species richness and species evenness in an area, was estimated using the Shannon diversity index, computed at the plot level as follows (Magurran, 1998):

$$\text{Diversity index } \mathrm{H}' = \sum_{i=1}^{s} \frac{n_i}{N} L_n \frac{n_i}{N}$$

where S = number of species; N = total number of weeds within the three quadrats in each plot; and = n_i number of individuals of the *i*th species within the three quadrats.

The relative abundance, which indicates how species are distributed within an ecosystem, was computed at the location level for each species as follows (Kent, 2012):

$$\text{relative density} = \frac{\text{Number of individuals of target species}}{\text{Number of individuals of all the species}}$$

$$\text{relative frequency} = \frac{\text{Number of target species}}{\text{Number of all species}}$$

$$\text{relative abundance} = \frac{\text{Relative density} + \text{relative frequency}}{2}$$

Multiple indices, which are not interchangeable, were used to enhance an understanding of complex relations driving the changes in weed density and composition during the transition to NT. To meet the assumptions of parametric analysis, a (x+0.5) transformation was performed before analysis to homogenise variances. An independent sample-paired *t* test was used to compare the total weed density and Shannon diversity index in NT and CONV systems, three different sampling times (3, 6 and 9 WACE) and on different soil types (clay loam, sandy loam and loam). The total weed densities at each sampling time and within the different soil types and years were tested separately using PROC TTEST (SAS Institute 9,2) with $\alpha = .05$. Repeated measures analysis was performed for weed density under different tillage and soil properties over different sampling times using a linear mixed model. Each analysis consisted of fixed effects of tillage, soil type, sampling time and all interactions. Wald-type F statistics were calculated for tillage, soil type, sampling time and all associated interactions using the SAS® statistical package. The standard error of difference (SED) was used for mean separation when treatments were significantly different ($p < .05$).

3 RESULTS

3.1 Weather data

The fields in this study had similar rainfall patterns with the greatest linear distance between two of the eighteen selected fields being 25 km. Precipitation was more evenly distributed during the 2009/2010 season than the 2010/2011 season (Figure 1A). The precipitation in January 2011 was above average and exceeded the 30-year average by 53.4%. There was no precipitation in February 2011. The monthly average temperatures for the 2009/2010 and 2010/2011 seasons were similar and comparable to the 30-year average (Figure 1B).

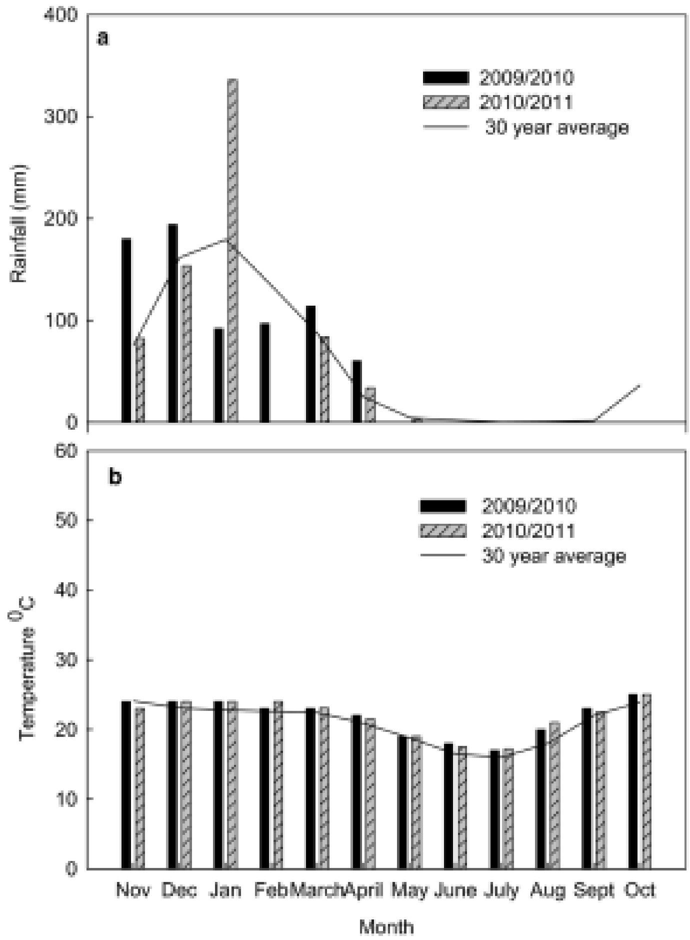

Fig. 1. Monthly precipitation and temperature during the 2009/2010 and 2010/2011 crop growth seasons, and the 30-year averages across all study sites

3.2 Weed composition across sites, tillage system and sampling time

Twenty-seven (27) weed species were identified across the three locations, (Table 2) with 41% of the total weed species being found in all three locations with different soil textures. For each soil type, abundance values >0.1 were considered as dominant weeds. The most dominant weed species in sandy loam and clay loam soils was *Richardia scabra*, whilst *Leucas martinicensis* was the most dominant weed in loam soils.

Table 2. The relative abundance of weed species identified during 2009/2010 and 2010/2011 seasons

Family	Weed species	Loam	Sandy loam	Clay loam
Amaranthaceae	*Amaranthus hybridus* L.	0.001	0.027	0.006
	Amaranthus retroflexus L.	0.001	0.001	-
Asclepiadaceae	*Asclepias syriaca* L.	-	0.002	-
Asteraceae	*Bidens pilosa* L.	0.156	0.234	0.086
	Leucas martinicensis (Jacq.) Ait.f.	0.176	0.217	0.039
	Acanthospermum hispidum D.C.	0.019	0.199	0.113
	Tridax procumbens L.	0.095	0.094	0.010
	Tagetes minuta L.		0.040	
	Galinsoga parviflora Cav.	0.033	-	0.006
Boraginaceae	*Trichodesma zeylanicum* (Burm. f.) R. Br.	0.004	-	0.010
Convolvulaceae	*Ipomoea plebia* (R.) Br	0.018	0.098	0.124
Cyperaceae	*Cyperus esculentus* L.	-	-	0.001
Euphorbiaceae	*Euphorbia hirta* L.	-	0.002	0.002
Fabaceae	*Acacia longifolia* (Andrews.) Willd.	0.023	0.015	0.038
Malvaceae	*Corchorus olitorius* L.	0.108	0.109	0.023
	Hibiscus calyphyllus Cav.	-	-	0.013
Poaceae	*Melinis repens* (Willd.) Zizka	0.060	0.278	0.096
	Rottboellia cochinchinensis (Lour.) W.D. Clayton	0.032	0.126	-
	Eragrostis aspera (Jacq.) Nees	0.029	0.099	-
	Eleusine indica L. Gaertn.	0.001	0.050	0.008
	Urochloa panicoides P. Beauv.	0.033	0.040	-
	Poa compressa L.	-	0.024	-
	Dactyloctenium aegyptium (L.) Willd.	0.022	-	0.075
	Phleum pratense L.	-	-	0.004
	Perotis patens Gand.	-	0.020	0.001
Portulacaceae	*Portulaca oleracea* L.	-	0.001	0.001
Rubiaceae	*Richardia scabra* L.	0.043	0.322	0.283

1 Note

3 Relative abundance = (relative density + relative frequency)/2).

3.3 Effects of the tillage system, soil type and sampling time on total weed density

The effect of tillage ($p < .05$) on total weed density at 3 WACE was significant in loam and clay loam soils during both seasons as recorded in (Table 3). Weed emergence was not affected by tillage in sandy loam soils at all the sampling times, in both seasons. The study findings revealed that in loam soils, the total weed density was 76% and 96% higher for NT than for CONV at 3 WACE during the 2009/2010 and 2010/2011 seasons, respectively. As to the other related findings, they revealed that in clay loam soils, the total weed density for NT was 37% and 33% higher than for CONV for the 2009/2010 and 2010/2011 seasons, respectively, at 3 WACE. At 6 WACE during the 2009/2010 and 2010/2011 seasons and at 9 WACE in 2009/2010 season, the weed densities in NT and CONV were similar.

Table 3. Mean total weed density (plant/m 2) in cotton (2009/2010) and maize (2010/2011) as affected by tillage system

Total weed density (plant/m²)							
		2009/2010			2010/2011		
Soil type	Tillage system	3 WACE	6 WACE	9 WACE	3 WACE	6 WACE	9 WACE
Loam	NT	9.72[a]	7.74	4.59	11.19	9.51	-
	CONV	5.52	7.34	3.89	5.71	10.87	-
	p-value	<.000	.155	.320	<.001	.270	-
Sandy loam	NT	13.79	13.94	10.82	15.49	14.94	-
	CONV	13.47	13.24	9.97	15.09	15.10	-
	p-value	.701	.685	.514	.474	.857	-
Clay loam	NT	9.17	7.73	5.64	10.22	8.12	-
	CONV	6.71	7.98	5.87	7.68	8.23	-
	p-value	.002	.156	.717	.024	.165	-

Abbreviations: CONV, Conventional tillage; NT, No-till; WACE, weeks after crop emergence.

[a] Square root transformed (x + 0.5) data presented.

3.4 Effects of tillage system, soil type and sampling time on dominant weed species (2009/2010 se...

Densities of dominant weed species were influenced by various interactions, including tillage × time of sampling, tillage × soil type, and time of sampling × soil type (Table 4). The tillage × time of sampling interaction was significant for *Melinis repens* and *L. martinicensis*, whilst no significant effect of tillage was observed at 6 WACE for *Melinis repens*. However, higher weed densities were observed under NT than under CONV at 3 and 9 WACE (Supplementary Table S1). The densities of *L. martinicensis* were higher under CONV than under NT at 6 WACE, whilst at 9 WACE, NT had higher weed density than CONV had. The interactive effect of tillage × soil type was significant for *M. repens* and *R. scabra*. On loam and clay loam soils, *Melinis repens* was found to have higher weed densities under NT than under CONV systems, whilst *R. scabra* was also found to have higher weed densities under NT on sandy loam and clay loam soils than CONV (Supplementary Table S2). The weed sampling time × soil type interaction was significant for all dominant weed species (Table 4). The weed densities were similar from 6 to 9 WACE for *M. repens*, under loam and clay loam soils. In contrast, the weed densities peaked at 6 WACE for *A. hispidum*, *B. pilosa*, *C. olitorius* and *L. martinicensis*, on sandy loam soils (Supplementary Table S3).

Table 4. Significance of the sources of variation for densities of dominant weeds occurring in plots subjected to no-till and conventional tillage treatments

Weed species	Source of variation: Tillage system (TS)	Time (T)	Soil type (ST)	TS × T	TS × ST	T × ST	TS × T × ST
2009/2010 season							
Melinis repens (Willd.) Zizka	.005	<.0001	<.001	.017	.018	<.001	.482
Acanthospemum hispidum D.C.	.779	<.001	<.001	.330	.248	<.001	.985
Bidens pilosa L.	.513	<.001	<.001	.056	.378	<.001	.620
Cochorus olitorius L.	.597	.006	<.001	.083	.555	<.001	.069
Ipomoea plebia (R.) Br.	.035	.338	.010	.214	.956	<.001	.136
Leucas martinicensis (Jacq.) Ait. f.	.132	<.001	<.001	<.001	.092	<.001	.142
Richardia scabra L.	.334	.022	<.001	0.855	.028	<.001	.449
Tridax procumbens L.	.022	<.001	< .001	.218	.090	<.001	.396
2010/2011 season							
Melinis repens (Willd.) Zizka	.005	<.0001	<.001	<.001	.607	<.001	<.001
Acanthospemum hispidum D.C.	.314	.023	<.001	.673	.534	<.001	.177
Bidens pilosa L.	.130	<.001	<.001	<.001	.554	<.001	.005
Cochorus olitorius L.	.634	.003	<.001	.417	.056	<.001	.758
Ipomoea plebia (R.) Br.	.851	.004	<.001	.116	.568	<.001	.007
Leucas martinicensis (Jacq.) Ait. f.	.998	<.001	<.001	.099	.006	<.001	.018
Richardia scabra L.	.016	<.001	<.001	.764	.166	<.001	.522
Tridax procumbens L.	.908	<.001	<.001	.218	.464	<.001	.042

Note: 6 *p*-values are from the analyses of variance for the 2009/2010 and 2010/2011 seasons.

Abbreviations: ST, soil type; T, sampling time; TS, Tillage system.

3.5 Effects of tillage system, soil type and sampling time on dominant weed species (2010/2011 season

The densities of *M. repens*, *Bidens pilosa, I. plebia, L. martinicensis* and *T. procumbens* were significantly affected by tillage system × sampling time × soil type interactions (Table 4). The effect of a tillage system on *I. plebia* was observed just in clay loams at 3 and 6 WACE (Supplementary Table S4). The NT system promoted an earlier emergence of *B. pilosa* on loam soils as compared to that of CONV, resulting in higher densities of *B. pilosa* at 3 WACE than at 6 WACE (Supplementary Table S4).

A significant sampling time × soil type interaction was observed for *Corchorus olitorius* and *A. hispidum* densities (Table 4). *C. olitorius* resulted in higher weed density at 6 WACE than at 3 WACE on loam and clay soils, whilst the sandy loam soils produced a higher density of *C. olitorius* at 3 WACE than at 6 WACE (Supplementary Table S5). The density of *A. hispidum* at 3 WACE was higher than that observed at 6 WACE in sandy loam soils. A reverse trend was observed in clay loam soils, where the weed density was higher at 6 WACE as compared to 3 WACE (Supplementary Table S5).

3.6 Effect of tillage system, soil type and sampling time on weed community diversity

A significant ($p < .05$) effect of tillage systems on the Shannon diversity indices at 3 WACE was observed on loam and clay loam soils during the 2009/2010 and 2010/2011 seasons (Figure 2). With regard to NT, the Shannon diversity indices were 142 and 75% higher than in CONV on loam soils during the 2009/2010 and 2010/2011 seasons, respectively. NT resulted in a 93% and 100% higher effect on the Shannon diversity index at 3 WACE on clay loam soils, during the 2009/2010 and 2010/2011 seasons, respectively. The effect of the tillage system**s** on weed diversity on clay loam soils at 6 and 9 WACE resulted in a 47% and 16% higher Shannon diversity index in NT than in CONV, respectively. There was no significant ($p > .05$) effect of the tillage system on weed diversity on sandy loam soils during both seasons.

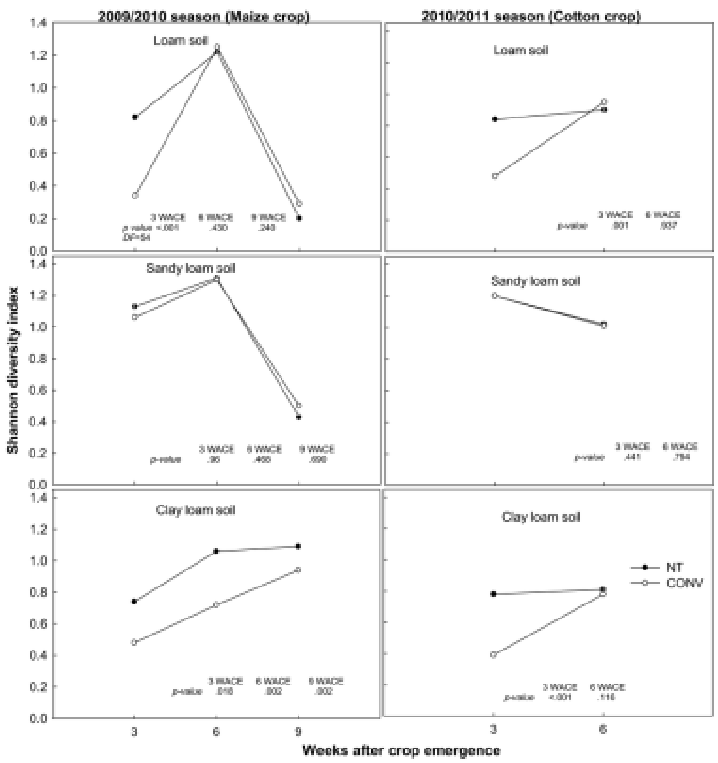

Fig 2. Effects of tillage system on weed diversity (Shannon diversity index) during the 2009/2010 and 2010/2011 seasons. NT: no-till; CONV: conventional tillage

4 DISCUSSION

NT tended to promote both a high and earlier weed emergence on loam and clay loam soils during both seasons, as compared to the effects of CONV systems. However, NT had no visible effect on the dynamics of weed emergence on sandy loam soils, thus indicating that the effects of the tillage system**s** vary in relation to soil characteristics. The findings concur with several other investigations that have reported higher weed densities under NT in loam and clay loam soils (Mhlanga *et al*., 2015; Hossain *et al*., 2017; Mashingaidze *et al*., 2017). No-till seed banks are concentrated in the top layer of the soil, where a higher proportion of NT seed banks germinate compared to CONV seed banks (Singh *et al*., 2015). Conversely, the lower weed density in CONV was attributed to the effect of the plough as it turns the soil and buries more weed seeds to a depth where conditions induce seed dormancy (Swanton *et al*., 2000). The influence of soil texture on the germination of seeds could possibly be associated with the transmission of light through the soil, which is dependent on soil particle size, moisture content, particle colour and the presence of organic matter (Benvenuti, 1995). Thus, variation in light attenuation might have contributed to soil effects on the emergence of weeds from the first 4 mm of soil. However, since weed emergence most probably occurred from seeds buried deeper than 4 mm, therefore, variation in light was probably not the only, or primary, causal factor of the effects caused by soil type.

The effects of tillage systems on individual weed species differed according to soil type and sampling time. Species like *M. repens*, *B. pilosa, I. plebia, L. martinicensis* and *T. procumbens* were conditioned by soil type × sampling time × tillage system interaction. The significant interaction demonstrates that the changes in weed density under NT cannot be attributed to tillage alone and that emergence responses to changes in a tillage system are regulated by species, sampling time and soil type. The different weed densities observed during the three sampling times might have been due to species-specific requirements for temperature, light and the soil water content required for germination. The lower weed density at 6 and 9 WACE compared to 3 WACE was likely due to the changing sub-canopy light quality and quantity, affecting weed growth. When comparing the weed densities at each assessment period between the two seasons, the effect of tillage on weed density was not magnified in the second season. The reason being that the plots were weeded effectively such that there were no weeds, which produced seeds and added more seeds to the weed seed bank reducing the potential cumulative effects of CT on weeds during the transition period.

The high weed densities of *M. repens* and *B. pilosa,* under NT, may necessitate earlier weeding than would be the case in CONV for loam and clay loam soils. High densities of *M. repens,* and *B. pilosa*, if not appropriately controlled, will result in yield losses. *Bidens pilosa* is competitive with crops, partly because this species is characterised by high water use efficiency and high nutrient extraction capacity (Santos and Cury, 2011). According to Takano *et al*. (2016), *Bidens pilosa* also features biotypes resistant to some herbicides, rendering its control difficult in agricultural areas. The management of *B. pilosa* is further complicated by prolonged periods of propagule dissemination, seed germination and seedling emergence, as well as the potential for beneficial associations between *B. pilosa* and microorganisms (Santos and Cury, 2011). *Melinis repens* is known as a prolific seed producer and can form a vegetative mat 5 cm thick across the soil surface (Stokes *et al*., 2011). Generally, early emerging weeds not specific to *M. repens* and *B. pilosa*, if not controlled effectively, are able to produce a higher number of weed seeds and in this manner contribute to future weed infestations (Simard and Benoit, 2012).

Whilst no significant effects on diversity were observed on sandy loam soils in this study, a higher diversity of weed species was observed in NT on loam and clay loam soils, depending upon the weed sampling time. High weed species diversity was also observed in emerged weeds under NT in maize–soybean winter wheat rotation**s** (Murphy *et al*., 2006). As previously alluded to, the different effects of tillage on weed diversity in different soil types and sampling times observed in this study suggest an interaction of tillage, soil type and weed sampling time, on weed diversity. Additionally, local field histories could have contributed to differences in weed communities across the soil types. However, according to Gaston *et al*. (2001), clay soil binds more nutrients and has higher water-holding capacity than sandy soils, which might explain high weed diversities in clay soil when compared with the lesser amount of diversities found in sandy soils. According to Ługowska *et al*. (2016), the highest Shannon index values were obtained for weed communities growing on silty loam soils, whilst the lowest Shannon index was found for weed communities observed on infertile soils which had developed from sand and slightly sandy loams. The high diversity indices in clay and loam soils found under NT, may have weed management implications. A more diverse weed community may be easier to manage than a less diverse one if the latter is dominated by more-difficult-to-manage weed species.

4.1 Divergent findings

In contrast to our results, Hernandez Plaza *et al*. (2011) compared NT and CONV systems in cereal–leguminous rotations that were practised for 23 years in Central Spain. They concluded that tillage does not significantly determine weed diversity. The short-term nature of our study makes it difficult to compare with the study by Hernandez Plaza *et al*. (2011). Explicitly, our data do not indicate whether the observed changes in weed diversity are lasting consequences of NT or due to an artefact related to the change in the tillage system. Shortly after the transition from CONV to NT, there could be a transitory period when new species adapted to NT began to populate a site, and species adapted to CONV continued to emerge from persistent but diminishing seed banks. This would elicit a temporary increase in diversity, and this could happen even though NT might not affect weed diversity in the long term (Odhiambo *et al*., 2015). The variation in findings between long- and short-term studies of the effect of tillage on weed diversity suggests that longitudinal studies under different conditions are necessary to disentangle the effects of tillage on weed diversity.

5 CONCLUSIONS

Effective weed management options are crucial to achieving potential yield gains offered by NT systems. In such systems, weed populations are, over time, reduced by crop rotations, appropriately timed control interventions and soil cover with crop residues and live mulches that inhibit weed seedling emergence and promote weed seed mortality (Wall, 2007). To successfully manage weeds during transition from CONV to NT, Zimbabwean smallholder farmers who have loam and clay loam soils will require new weed management schedules. This is because the results of this study indicated that NT induced both denser and earlier weed emergence on loam and clay loam soils, compared to the CONV tillage-based systems at 3 WACE. According to our findings, farmers with fields in transition to NT need to remove weeds earlier than those with fields under CONV; a large number of weeds immediately following transition to NT could be discouraging to the farmers. However, there is a need for long-term studies because NT-induced increases in weed density and diversity could be a temporary phenomenon.

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REFERENCES

Abbasvand, E., Hassannejad, S., Shafagh-Kolvanagh, J. and Zehtab, S. (2020) Altitude and soil properties affected grassland and weed distribution. *Journal of Biodiversity and Environmental Sciences*, 4, 231 – 235.

Bàrberi, P., Bonari, E., Mazzoncini, M., Garcia-Torres, L., Benites, A. and Martinez-Vilela, A. (2001) *Weed density and composition in winter wheat as influenced by tillage systems. Conservation agriculture, a worldwide challenge*. Proceedings of the first world congress on conservation agriculture, Madrid, Spain, 1–5 October (2001), pp 451 – 455.

Benvenuti, S., (1995) Soil light penetration and dormancy of Jimsonweed (*Datura stramonium*) seeds. *Weed Science*, 43, 389 – 393.

Food and Agriculture Organisation (FAO)/United Nations Educational, Scientific And Cultural Organization (UNESCO) (1974) *Soil Map of the World*. Volume 1, Legend. UNESCO, Paris, 62 p.

Fried, G., Norton, L.R. and Reboud, X. (2008) Environmental and management factors determining weed species composition and diversity in France. *Agriculture, Ecosystems & Environment*, 128 (1-2), 68 – 76. https://doi.org/10.1016/j.agee.2008.05.003

Gaston, L.A., Locke, M.A., Zablotowicz, R.M. and Reddy, K.N. (2001) Spatial variability of soil properties and weed populations in the Mississippi Delta. *Soil Science Society of America Journal*, 65, 449 – 459.

Gee, G.W. and Bauder, J.W. (1986) Particle size analysis. In: Klute, A. (Ed.) *Methods of soil analysis. Physical and mineralogical methods. Agronomy Monograph*, 2 nd edition, Volume 9, Madison, Wisconsin, USA : American Society of Agronomy, pp. 383 – 411.

Plaza, E.H., Kozak, M., Navarrete, L. and Gonzalez-Andujar, J.l. (2011) Tillage system did not affect weed diversity in a 23-year experiment in Mediterranean dryland. *Agriculture, Ecosystems & Environment,* 140 (1-2), 102 – 105. https://doi.org/10.1016/j.agee.2010.11.016

Hossain, M.M., Begum, M., Rahman, M.M., Hashem, A., Bell, R.W. and Haque, M.E. (2017) *Weed seed bank dynamics in long term trials of conservation agriculture 2nd conference on conservation agriculture for smallholders (CASH-II) 14–16 February 2017*, *Mymensingh, Bangladesh*. pp 41 – 42.

Kent, M. (2012) *Vegetation description and data analysis*. Hoboken, NJ : Wiley Blackwell.

Ługowska, M., Pawlonka, Z. and Skrzyczyńska, J. (2016) The effects of soil conditions and crop types on diversity of weed communities. *Acta Agrobotanica*, 69, 1687.

Magurran, A.E. (1998) *Ecological diversity and its measurement*. Princeton, NJ : Princeton University Press, p. 128.

Mafongoya, P., Rusinamhodzi, L., Siziba, S. et al (2016) Maize productivity and profitability in Conservation Agriculture systems across agro-ecological regions in Zimbabwe: A review of knowledge and practice. *Agriculture Ecosystems & Environment*, 220, 211 – 225.

Mashingaidze, N., Madakadze, I.C. and Twomlow, S.J. (2012) Response of weed flora to conservation agriculture systems and weeding intensity in semi-arid Zimbabwe. *African Journal of Agricultural Research*, 36, 5069 – 5082.

Mashingaidze, N., Twomlow, S., Madakadze, I.c., Mupangwa, W. and **Mavunganidze**, Z. (2017) Weed growth and crop yield responses to tillage and mulching under different crop rotation sequences in semi-arid conditions. *Soil Use and Management*, 33, 311 – 317.

Mohler, C.L. (1993) A model of the effects of tillage on emergence of weed seedlings. *Ecological Applications*, 3, 53 – 73.

Mtambanengwe, F., Nezomba, H., Tauro, T., Chagumaira, C., Manzeke, M. and Mapfumo, P. (2015) Mulching and fertilization effects on weed dynamics under conservation agriculture-based maize cropping in Zimbabwe. *Environments*, 2, 399 – 414.

Mhlanga, B., Cheesman, S., Maasdorp, B., et al (2015) Weed community responses to rotations with cover crops in maize-based conservation agriculture systems of Zimbabwe. *Crop Protection*, 69, 1 – 8.

Muoni, T. and Mhlanga, B. (2014) Weed management in Zimbabwe smallholder conservation agriculture farming sector. *Asian Journal of Agriculture and Rural Development*, 4 (142), 47 – 57.

Murphy, S.D., Clements, D.R., Belaoussoff, S., Kevan, P.G. and Swanton, C.J. (2006) Promotion of weed species diversity and reduction of weed seedbanks with conservation tillage and crop rotation. *Weed Science*, 54, 69 – 77.

Nicole, L. and Thierfelder, C. (2017) Weed control under conservation agriculture in dryland smallholder farming systems of southern Africa. A review. *Agronomy for Sustainable Development*, 37, 48. https://doi.org/10.1007/s13593-017-0453-7

Nkoa, R., Owen, M.D.K. and Swanton, C.J. (2015) Source weed abundance, distribution, diversity, and community analyses. *Weed Science*, 63, 64 – 90.

Nyamangara, J., Mashingaidze, N., Masvaya, E.N. et al (2014) Weed growth and labour demand under hand-hoe based reduced tillage in smallholder farmers' fields in Zimbabwe. *Agriculture Ecosystems & Environment*, 187, 146 – 154.

Odhiambo, J.A., Norton, U., Ashilenje, D., Omondi, E.C. and Norton, J.B. (2015) Weed dynamics during transition to conservation agriculture in western Kenya maize production. Gonzalez-Andujar JL, ed. *PLoS One*, 10 (8), e0133976. https://doi.org/10.1371/journal.pone.0133976

Santos, J.B. and Cury, J.P. (2011) Blackjack: A special weed in tropical soils. *Planta Daninha*, 29, 1159 – 1172.

Singh, V., Barman, K., Singh, R. and Sharma, A. (2015) Weed management in conservation agriculture systems. In: Farooq, M. and Siddique, K. (Eds.) *Conservation Agriculture.* Cham, Switzerland : Springer, pp. 39 – 77.

Simard, M.J. and Benoit, D.L. (2012) Potential pollen and seed production from early- and late-emerging common ragweed in corn and soybean. *Weed Technology*, 26, 510 – 516.

Swanton, C.J., Shretha, D.R., Clements, B., Booth, D. and Chandler, K. (2000) Evaluation of weed management systems in a modified no-tillage corn soybean wheat rotation. Weed densities crop yields and economics. *Weed Science*, 50, 505 – 511.

Stokes, C.A., Macdonald, G.E., Adams, C.R., Langeland, K.A. and Miller, D.L. (2011) Seed biology and ecology of natalgrass (Melinis repens). *Weed Science*, 59, 527 – 532.

Takano, H.K., Oliveira Junior, R.S.d., Constantin, J., Braz, G.B.P., Franchini, L.H.M. and Burgos, N.R. (2016) Multiple resistance to atrazine and imazethapyr in hairy beggarticks (Bidens pilosa). *Ciência e Agrotecnologia*, 40 (5), 547 – 554. https://doi.org/10.1590/1413-70542016405022316

Vasileiadis, V.P., Froud-Williams, R.J. and Leftherohorinos, I.G. (2012) Tillage and herbicide treatments with inter-row cultivation influence weed densities and yield of three industrial crops. *Weed Biology and Management*, 12 (2), 84 – 90. https://doi.org/10.1111/j.1445-6664.2012.00440.x.

Wall, P.C. (2007) Tailoring conservation agriculture to the needs of small farmers in developing countries. *Journal of Crop Improvement*, 19, 137 – 155.