Effects of crop residues and reduced tillage on macrofauna abundance

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Abstract

Conservation agriculture is promoted to safeguard resilient properties of soils and to reclaim degraded arable lands. This is achieved through creating necessary conditions for fauna recolonisation. A study was carried out at Kadoma and Southeast Lowveld of Zimbabwe to assess the effects of conservation agriculture practices on soil macrofauna diversity in the 2008-2009 agricultural season. A randomized complete block design experiment, where four crop residue levels (0t/ha, 2t/ha, 4t/ha and 6t/ha) were replicated four times on un-tilled plots at five sites, was used. Soil fauna found in collected monoliths were identified and quantified. Analysis of variance showed significance (P<0.001) in site and treatment effects on both macrofauna abundance and diversity. Reduced tillage with residue cover yielded significantly (P<0.05) higher species richness and macrofauna abundance than conventional systems. There was a significant correlation (r^2=0.767) between residue amount and species richness. Although there was no apparent consistent relationship between treatment and species richness, diversity and evenness; abundance was in the order 6t/ha>4t/ha>2t/ha>0t/ha>Conventional systems. The major macrofauna groups observed were termites, ants and beetle-larvae. It was concluded that short-term conservation agriculture systems has significantly positive effects on macrofauna species richness and abundance, which are crucial for initiating soil regeneration. The results are discussed in the context of sustainable crop production using conservation agriculture by resource poor farmers.

Key words: Conservation agriculture, residue cover, fauna recolonisation, planting basins, Shannon-Wiener diversity and evenness indices.

Introduction

Conservation Agriculture (CA) is defined as a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment (FAO, 2007). It is premised on three key principles, namely, minimum mechanical soil disturbance, permanent soil cover and diverse crop rotations (ACT, 2005; FAO, 2008). Adoption of CA has advanced rapidly in America and Australia, mainly on large mechanized commercial farms (Derpsch, 2005). However, adoption amongst African smallholder farmers, who make up the majority of food producers' on the continent, has been very slow owing to a

host of challenges. Considerable areas under smallholder farmer CA were only reported in Ghana (Ekboir *et al*, 2002), Zambia (Haggblade & Tembo, 2003), Tanzania (Shetto & Owenya, 2007) and Zimbabwe (FAO, 2007). CA is adapted to suit specific farmer practices which are heavily dependent on available resources and farmer preferences. Its form varies from country to country and also from farmer to farmer. For example, Zimbabwean smallholder farmers practise a form of CA locally known as conservation farming. It is based on hand-hoe made planting basins and application of soil cover at planting or soon after crop emergence (Harford *et al*, 2009).

Conventional agriculture (Conv) which heavily relies on mouldboard-plough tillage practices is known to be the major driver of soil degradation (Elwell, 1985; Whitlow, 1987) through increased depletion of organic matter and nutrients (Chivenge *et al*, 2007; Gwenzi *et al*, 2009). CA is, therefore, promoted to address challenges posed by conventional agricultural practices. Reduced soil disturbance and application of soil cover provide conditions that favour soil fauna recolonisation of the degraded areas; starting with relatively big-sized organic material primary shredders, followed or accompanied by progressively small-sized fauna groups as the decomposition process becomes more complex. The "early invaders", the macrofauna group, are generally understood to be important for propagation of pores which give soils their characteristic open structures to facilitate air circulation, water infiltration and root development (Anderson, 1988).

The practice of CA, where zero tillage and soil cover are adopted, has demonstrated significant contributions to increased soil macrofauna. Studies in Zimbabwe by Nhamo (2007) observed significantly higher macrofauna populations in conservation agriculture systems than conventional systems due to improved soil surface micro-climates and organic matter availability on soil surface. These observations are, however, based on long-term CA trials, hence not much is known on whether CA practices would have a significant influence on soil fauna in the short-term. Other long-term CA benefits include reduced soil erosion and improved soil moisture storage (Nyagumbo, 2008). In tropical Brazil (Landers, 2008) and semi-arid Australia (Blank, 2008), CA practice was reported to have aided natural rehabilitation of degraded arable soils despite agriculture being highly mechanized in these two economies. Its potential for degraded soil rejuvenation on African smallholder farms is not well understood, and their practice significantly differs from that in developed countries. In the African smallholder farmer context, CA is highly adapted and promoted to mitigate socio-economic challenges like acute labour shortages and making more efficient use of resources (FAO, 2002).

There is a general lack of empirical data, in developing countries, on the effects of CA practices on macrofauna abundances and diversity; yet the same soil organisms are essential for initiating rehabilitation of degraded soil and maintaining its resilience. Soil organisms carry out a range of important processes for soil health and fertility in both natural ecosystems and agricultural systems. In addition to performing the vital functions in soils, they also make up diversity of life in soil. This soil biodiversity, comprising organisms that spend all or a portion of their life cycles within the soil or on its immediate surface, is an important but poorly understood component of terrestrial ecosystems. This research investigated the impacts of using planting basins with residue cover on soil macrofauna diversity over a single typical Zimbabwean agricultural season.

Materials and Methods

Site description

The research was carried out on five sites situated in two agro-climatic zones of Zimbabwe; namely agro-climatic zone III and V. Four sites were located 50-km south of Chiredzi town (21° 03' E; 31° 40' S and 450 masl) in the Southeast Lowveld of Zimbabwe (SELZ) which is in agro-climatic zone V (also known as NRV). This region is characterized by low and erratic rainfall averaging less than 450 mm per year. Rainfall is so erratic that 5% of the seasons do not receive any rainfall at all (Morse, 1996). The recommended farming system for this region is extensive cattle and/or game ranching on natural pastures (Vincent and Thomas, 1960). One site was located 20-km south of Kadoma town (18° 21'E; 29° 55' S and 1156 masl) in agro-climatic zone III (also known as NRIII). The recommended farming system for this region is semi-intensive farming based on mixed crop and livestock systems, because rainfall is moderate (averaging 650 to 800 mm per year), but the zone is still prone to severe mid-season dry spells (Vincent and Thomas, 1960).

Chemical and chemical properties of the soils

The physical and chemical properties of the soils from the five sites are depicted in Table 1.

Table 1. Characteristics of soils from different sites before setting up of experiments.

Agro-zone	NR V				NR III
Site No.	1	2	3	4	5
Soil type*	Luvisols	Vertisols	Vertisols	Vertisols	Luvisols
% OC	0.59	1.72	1.22	1.02	1.30
% Clay	8	20	16	15	33
% Silt	4	15	17	14	18
% Sand	88	65	67	71	49
pH (CaCl$_2$)	6.5	7.4	7.8	7.6	5.4
N (ppm)	17	2	8	44	14
P (ppm)	1	2	1	20	3
K (cmol kg^{-1})	0.39	1.28	0.72	0.69	0.30
Ca (cmol kg^{-1})	3.46	11.43	44.74	33.55	9.08
Mg (cmol kg^{-1})	1.48	4.22	4.29	4.87	4.19
Na(cmol kg^{-1})	<0.001	0.40	0.20	0.17	0.04

Note: *NR = Agro-climatic zone (also known as Natural Region)*
        ppm = parts per million
        *Soil classification is according to FAO Soil units

Experimental design and treatments

Before the trials were set up, all the five sites were under low-input rain-fed cropping systems with ox-drawn plough tillage being the base of primary tillage operation; while the same implement together with hand-hoes were used for secondary tillage activities. Sorghum (*Sorghum vulgaris*) is the main grain (food) crop in NRV while maize (*Zea mays*) is the chief crop of NRIII. A randomized complete block design (RCBD) experiment

was set up at each site. Reduced-tillage (use of hand-hoes to make planting basins) and soil cover (using previous crop residues) formed the basis of conservation agriculture (CA) treatments while the control was based on conventional ploughing. All CA treatments and the control (Table 2) were replicated four times at each site. Soil cover was applied during planting. On the control plots, previous crop residues were ploughed under during tillage. Sowing was done with the first effective rains at each site, with a target of 38,000 plants ha^{-1} in conservation agriculture systems. Weed management was done by hand in CA systems and hand-hoe weeding in control plots. Basal fertilizer (7% N, 14% P_2O_5, and 7% K_2O) was applied at 400 kg ha^{-1} in NRIII; while top dressing (34.5% N) application was at 200 and 100 kg ha^{-1} for NRIII and NRV respectively.

Table 2. Summary of the different treatments used in the experiments.

Treatment	Explanation
CA$_{0t/ha}$	Hand-hoe made planting basins + no crop residue cover
CA$_{2t/ha}$	Hand-hoe made planting basins + crop residue cover at a rate of 2t/ha
CA$_{4t/ha}$	Hand-hoe made planting basins + crop residue cover at a rate of 4t/ha
CA$_{6t/ha}$	Hand-hoe made planting basins + crop residue cover at a rate of 6t/ha
Conv	Conventional tillage with no soil cover applied; residues were ploughed under

Note: *CA = Conservation Agriculture*
t/ha = tons per hectare

Sampling and analysis of macrofauna

Sampling for macrofauna was done only once at the end of 2008-2009 rainy season using the method of Anderson & Ingram (1993). The soil fauna was collected by sifting through monoliths of size 20cmx20cmx20cm from the plots. The monoliths were collected from 3 randomly selected plots of each treatment on each site. In total, fifteen monoliths were collected at each site. The collected macrofauna was identified and counted. Grouping and counting of individuals in each group was considered since the study was a quick test of the potential impacts of conservation agriculture practice on soil macrofauna abundance. Macrofauna abundance, diversity and evenness indices were computed using the Shannon-Wiener (1963) method and then analysis of variance (ANOVA) was done. The formulae used are:

Macrofauna species richness   **S = number of fauna groups present**
Macrofauna abundance (density)   **N = P/A**
Macrofauna diversity index   **H = - $\sum$ (P$_i$ ln P$_i$)**
Macrofauna evenness index   **E = H/lnS**

Where **P** = fauna population in soil specimen; **A** = surface area of monolith (20x20cm^2); **P$_i$** = the proportion of individuals in ith order estimated as n$_i$/N; where n$_i$ is the number of individuals in ith order.

Macrofauna abundance in our case represents the total number of individuals in a sample per unit area. Macrofauna diversity has two components i.e. species richness and evenness. While species richness is indicative of the number of different species present in the sample, the concept of evenness goes beyond that. It quantifies the relative

abundances of the different species in the samples. Therefore, evenness can best be regarded a measure of the equality of the individuals in the samples.

Results

Analysis of variance showed significant (P<0.001) treatments and sites effects on the results. Correlations between amount of crop residue cover applied in CA systems and abundance (Figure 1) and also species richness were positive.

Effects of reduced-tillage and soil cover on macrofauna abundance

The arthropods identified across the sites were grouped into termites (*Isoptera*), ants (*Hymenoptera*), beetles (*Coleoptera*) and centipedes (*Chilopoda*). The mean abundance of each species at each site and treatment are presented in Tables 3, 4 and 5.

Table 3. The effects of reduced-tillage and soil cover on termite abundance.[1]

Treatments	Site No.				
	Site 1	Site 2	Site 3	Site 4	Site 5
$CA_{0t/ha}$	225 a	263 a	97 a	294 a	394 a
$CA_{2t/ha}$	600 b	637 b	188 b	356 a	806 b
$CA_{4t/ha}$	1269 c	713 c	875 c	1332 b	1331 c
$CA_{6t/ha}$	6463 d	1356 d	6044 d	2644 c	1525 d
Conv	81 e	0 e	25 e	38 e	6 e

Table 4. The effects of reduced-tillage and soil cover on ant abundance.[1]

Treatments	Site No.				
	Site 1	Site 2	Site 3	Site 4	Site 5
$CA_{0t/ha}$	10 a	9 a	13 a	13 a	6 a
$CA_{2t/ha}$	19 b	13 b	13 a	19 a	6 a
$CA_{4t/ha}$	25 c	25 c	25 b	88 b	19 b
$CA_{6t/ha}$	38 c	38 d	44 c	106 b	50 c
Conv	0 d	6 e	13 a	0 c	0 d

Table 5. The effects of reduced-tillage and soil cover on centipede abundance.[1]

Treatments	Site No.				
	Site 1	Site 2	Site 3	Site 4	Site 5
$CA_{0t/ha}$	0 a	25 a	7 a	7 a	6 a
$CA_{2t/ha}$	0 a	25 a	7 a	13 b	13 b
$CA_{4t/ha}$	7 b	25 a	7 a	26 c	13 b
$CA_{6t/ha}$	7 b	56 b	13 b	44 d	25 c
Conv	0 a	0 c	0 c	0 e	0 d

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[1] Within a column of a table, reported quantities are significantly different where accompanied by different letters (p<0.05).

Table 6. The effects of reduced-tillage and soil cover on beetle-larva abundance.[2]

Treatments	Site No.				
	Site 1	Site 2	Site 3	Site 4	Site 5
$CA_{0t/ha}$	13 a	25 a	25 a	19 a	0 a
$CA_{2t/ha}$	25 b	31 a	44 b	31 b	6 b
$CA_{4t/ha}$	25 b	38 ab	50 b	38 b	13 c
$CA_{6t/ha}$	25 b	44 b	69 c	75 c	19 d
Conv	7 a	6 c	0 d	7 d	0 a

Termites were the most predominant macrofauna group across all the sites. There was a significantly higher macrofauna population in CA systems than conventional practice. This was true for all the groups; i.e. termites, ants, centipedes and beetle-larvae. In the CA systems, abundance increased with increasing amount of crop residues applied. However, the increments were not always significant. Abundance was influenced by amount of residues applied and also the weeds. Weeds from each plot were retained as soil cover during weeding operations. Millipedes (*Diplopoda*), earthworms (*Haplotaxida*), crickets (*Orthoptera*) and mites (*Acarina*) were also observed on a few occasions but their numbers were very low, hence they are not presented in the tables. In general, macrofauna abundance was in the order $CA_{6t/ha} > CA_{4t/ha} > CA_{2t/ha} > CA_{0t/ha} > Conv$ on all sites and soil types. Macrofauna abundance in CA systems was significantly correlated ($r^2 = 0.55$) to the amount of crop residues applied as soil cover (Figure 1).
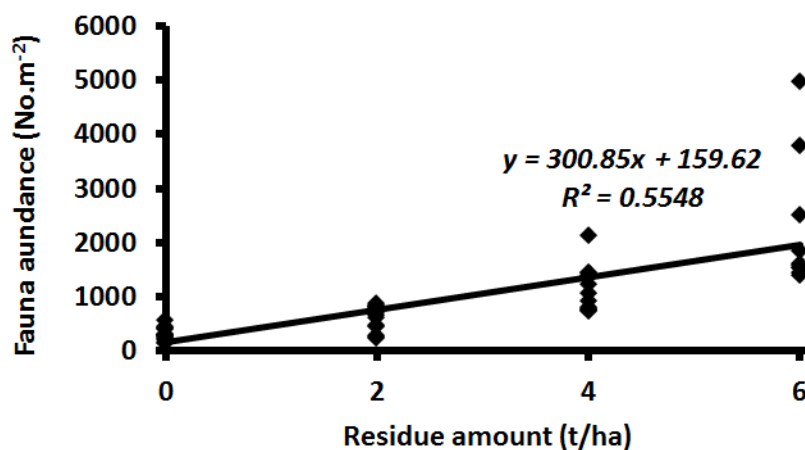
Figure 1. Correlation between amount of residues and macrofauna abundance in CA systems.

Effects of reduced-tillage and soil cover on species richness

The mean numbers of macrofauna groups observed in each treatment for all the five sites are presented in Table 7.

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[2] Within a column of a table, reported quantities are significantly different where accompanied by different letters (p<0.05).

Table 7 Reduced-tillage and soil cover effect on mean number of fauna groups.[3]

Treatments	Site No.				
	Site 1	Site 2	Site 3	Site 4	Site 5
$CA_{0t/ha}$	3 a	3.7 a	4 a	4 a	3 a
$CA_{2t/ha}$	3 a	4 a	4 a	4 a	4 b
$CA_{4t/ha}$	4 b	3.7 a	4 a	4 a	4 b
$CA_{6t/ha}$	3.7 b	4 a	4 a	4 a	4 b
Conv	2 c	2 b	2 b	2 b	1 c

The average number of fauna groups per treatment observed in CA systems was significantly higher than in conventional practice across all sites. Hence, mechanical soil disturbance had a negative influence on species richness. Soil cover did not have a significant influence on the number of fauna groups; however, there was a tendency for increasing number of fauna groups with crop residue amount. Species richness was not influenced by soil type.

Effects of reduced-tillage and soil cover on diversity and evenness indices

Figure 2 shows the relationships between treatment and indices that describe diversity and evenness on the different sites.

Site and treatment effects on macrofauna diversity and evenness were highly significant ($P<0.001$). Both diversity and evenness were influenced by treatments in the same ways at each site, as shown in Figure 2. The figure shows significantly higher ($P<0.05$) diversity and evenness indices for conventional systems (Conv) than CA systems with high levels of crop residue retention (i.e. $CA_{4t/ha}$ and $CA_{6t/ha}$) on sites in SELZ (i.e. sites 1. 2, 3 and 4 in NRV) where sorghum residues were used. In this zone, CA without residues ($CA_{0t/ha}$) also had comparatively higher diversity and evenness indices than CA systems with residue retention. The site in Kadoma (site 5 in NR III), onto which maize residues were retained, deviated from this pattern; instead diversity and evenness indices increased with residue amount. Diversity and evenness indices on this site were significantly higher ($P<0.05$) in $CA_{6t/ha}$ than other CA systems (i.e. $CA_{0t/ha}$, $CA_{2t/ha}$ and $CA_{4t/ha}$) and conventional system (where indices were close to zero).

Although the relationship between crop residue amount on the one hand and diversity and evenness indices, on the other hand, was not consistent across the sites, diversity and evenness were clearly higher in systems with no crop residues ($CA_{0t/ha}$ and Conv) than in CA systems with residues ($CA_{2t/ha}$, $CA_{4t/ha}$ and $CA_{6t/ha}$) where sorghum stover was used. However, the opposite was true for the case where maize stover was applied.

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[3] Within a column of a table, reported quantities are significantly different where accompanied by different letters (p<0.05).
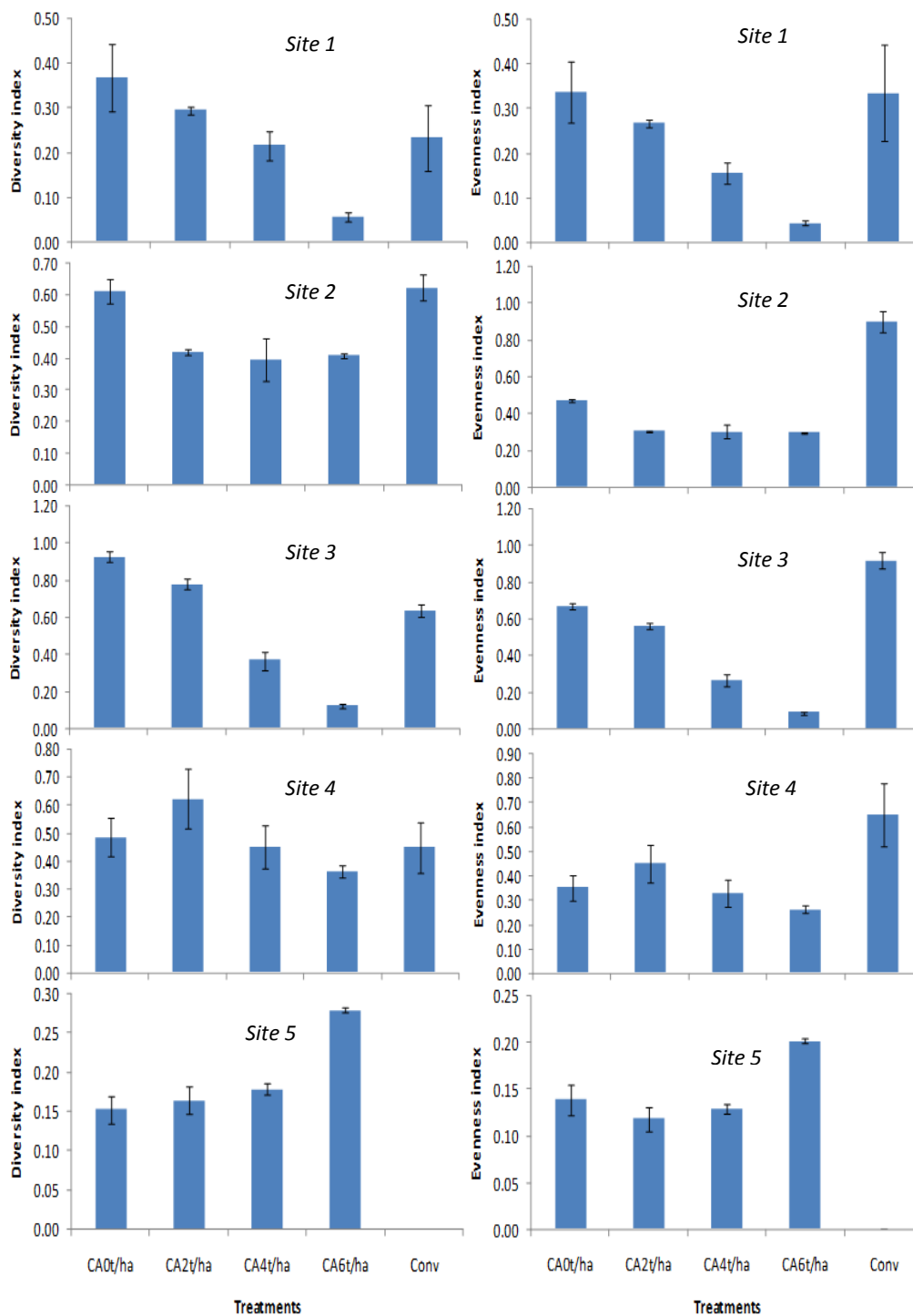
Figure 2. Effects of reduced tillage & soil cover on macrofauna diversity and evenness across sites (Note: error bars = standard errors of means).

Discussion

The most significant macrofauna group found across the sites was termites. Termites are renowned primary shredders of most dry organic materials; hence their populations tend to increase with increasing amounts of organic material applied as soil cover. The beetle-

larvae and ant groups were also important in comparison with the rest. The results show that CA has a profound effect on macrofauna density as well as diversity and an increase in macrofauna will aid in the increase in rate of decomposition of organic material. Although Nhamo (2007) observed soil type as an important determinant of fauna groups, soil type did not show a significant effect in this research. Agro-climatic zone did not have any effect on number of fauna groups because all four macrofauna groups were observed on sites in the two agro-climatic zones.

It appears quick and convenient to use the number of fauna groups (species richness) in assessing fauna community situations. Higher species richness would suggest a complex community with a high degree of species interaction; hence that community is capable of supporting higher levels of energy transfer, predation, competition and niche availability than other similar communities that exhibit lower species richness. The result of an improvement in species richness upon adoption of CA clearly demonstrates the importance of reduced tillage in protecting fauna activity and habitat. The addition of organic matter on soil surface further ameliorates soil conditions for better survival and support of more fauna groups. Woltering (2005) observed similar results where soil cover in the form of crop residues increased biological activity. However, the number of fauna groups alone does not give much information about community potential because no account of number of individuals per species or the evenness of individuals within each species is taken; hence it is seldom used for describing community structures. It is only important for initial inferences on condition of a given community. The concept of fauna abundance (or population) is, instead, used to describe the carrying potential for a system.

Fauna abundance is indicative of total number of individuals per unit area which are capable of living within the given environment. If the theory that higher species richness results in higher levels of energy transfer holds, then the same can be applied when fauna abundance is higher. In our study, macrofauna abundance was significantly higher in CA systems than conventional systems. Macrofauna abundance increased with the amount of crop residues applied, in the order $CA_{6t/ha} > CA_{4t/ha} > CA_{2t/ha} > CA_{0t/ha}$. Mutsamba *et al*. (2010) made a similar observation in an assessment of impact of residue amount on termite population. The strong correlation ($r^2 = 0.55$) between soil cover and macrofauna abundance suggests increasing capacity to support more soil fauna with additional crop residues. Increased macrofauna abundance would be important in rehabilitation of degraded soils and maintenance of agro-systems prone to serious capping.

It was interesting to note that diversity and evenness were affected in almost the same way by treatments at each site. In the case where sorghum residues were used, diversity and evenness were significantly higher in conventional and CA system without residue retention than CA with residue retention. A possible explanation to the decreasing diversity and evenness indices in our case could be that too high residue cover was detrimental for some fauna species development while favouring development of others. Termites were the most prominent macrofauna group where sorghum residues were used. Further evidence supporting higher diversity and evenness in conventional than CA systems could be that development of some macro-fauna (e.g. mites) are enhanced by tillage and appear to recover from tillage disturbances more rapidly (Reedler et al., 2006 & Wardle 1995). However, our results in the case where maize residues were used

agreed with the observations made by Verhulst et al. (2010) who reported an increased species diversity when reduced tillage was combined with residue retention. Therefore, species diversity and evenness appeared to depend on the quality of organic material retained on the soil surface.

Although the relationship between treatments and macrofauna diversity and/or evenness across sites was not consistent, termites became more dominant with soil cover application in the majority of cases. This is indicative of the fact that decomposition was generally in its early stages and the primary shredders (termites) of organic matter were the more active group. It would, therefore, be important to monitor dynamics of fauna diversity and evenness in longer term trials.

Conclusions

Conservation agriculture practices have potential to increase agricultural productivity through better efficiency in utilization of inputs and other resources due to improved soil conditions. The aspects of improved soil structure and fertility which were most pronounced in this study enhance greater environmental sustainability. This study showed that residue rate had significantly positive effects on macrofauna abundance; however the quality of organic material applied is important. Maize residue retention yielded superior macrofauna diversity and evenness indices under conservation agriculture practices than sorghum residue retention. In the short-term, conservation agriculture exhibited potential to attract higher levels of macrofauna and this is important as the initial stage in natural rehabilitation of degraded arable lands. Soil macrofauna are important regulators of decomposition, nutrient cycling, soil organic matter dynamics, and pathways for aeration and water movement as a consequence of their feeding and burrowing activities. Subsequent follow up studies would be important to ascertain soil regeneration in the medium to longer-term. Continuous sampling of fauna during the decomposition cycle would also be important to reduce biases associated with dominance of particular species at certain stages of the process.

Acknowledgements

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