ATATÜRK ÜNİVERSİTESİ YAYINLARI
ATATURK UNIVERSITY PUBLICATIONS

Research Article *Araştırma Makalesi* DOI:10.17097/agricultureatauni.1492131

Effect of soil nutrient management on soil weed seed bank dynamics across a soil fertility gradient in smallholder farms, Eastern Zimbabwe

Doğu Zimbabwe'deki küçük çiftliklerde toprak besin yönetiminin toprak verimliliği gradyanı boyunca toprak yabancı ot tohum bankası dinamikleri üzerindeki etkisi

Justin CHIPOMHO[1]
Cosmas PARWADA[2]
Nyamande MAPOPE[1]
Kennedy SIMANGO[1]

[1] Faculty of Plant and Animal Sciences and Technology, Department of Crop Science, Marondera University of Agricultural Sciences and Technology, Marondera, Zimbabwe.
[2] Tugwi Mukosi Multidisciplinary Research Institute, Midlands State University, Zvishavane, Zimbabwe.

ABSTRACT

Weed seed banks are latent biotic stress contributors to low crop production among smallholder farms. The objective of this study was to investigate effect of repeated soil nutrient amendments on weed seed bank dynamics in eastern Zimbabwe. Soil samples were taken from three farms with low, medium and high soil organic carbon (SOC) along the catena. Sampled treatments included varying combinations of compound D (7%N, 14%P, 7% K) fertiliser, cattle manure and lime. Weeds that emerged per plot were counted by species and data was tested for normality before running a linear mixed-effects model and Restricted Maximum Likelihood. Principal Component Analysis (PCA) was performed to establish the relationship between seasons, SOC, soil nutrient amendment, and emerged weeds. Significant ($p < .05$) species richness (Margalef index), and Shannon Weiner index were recorded in the medium (6.4g kg-1soil), high (8 g kg-1 soil) and low (< 3.9 g kg-1soil) SOC. Weed species emergence was significantly ($p < .05$) influenced by the level of SOC along the catena positions, representing results from the source. Emergency and abundance of weeds such as *Richardia scabra*, was associated with low SOC acidic sandy soils from the upper catena. However, application of nutrients (NPK+lime treatment) reduced weed species counts from 1.96±0.12 to 1.4±0.12. Cattle manure and NPK+CM treatments recorded significantly higher weed emergence, and weed biomass; compared to the control. Clearly, cattle manure treatments significantly increase the soil weed seed bank; thus, weeding intensity is likely to increase in cattle manure treated fields.

Keywords: Germination, organic matter, soil nutrients, weed diversity, weed management

ÖZ

Yabancı ot tohum bankaları, küçük ölçekli çiftçilik işletmelerinde düşük ürün üretimine katkıda bulunan gizli biyotik stres faktörleridir. Bu çalışmanın amacı, tekrarlanan toprak besin değişikliklerinin Doğu Zimbabve'de yabancı ot tohum bankası dinamikleri üzerindeki etkisini araştırmaktır. Toprak örnekleri, eğim boyunca düşük, orta ve yüksek toprak organik karbon (TOC) içeren üç çiftlikten alınmıştır. Örneklenen işlemler arasında bileşik D (7% N, 14% P, 7% K) gübresinin farklı kombinasyonları, sığır gübresi ve kireç bulunmaktadır. Parsel başına çıkan yabancı otlar türlerine göre sayılmış ve veriler normal dağılıma sahip olmadan önce bir lineer karışık etkiler modeli ve Sınırlı Maksimum Olabilirlik çalıştırılmıştır. Başlık Bileşen Analizi (PCA), mevsimler arası ilişkiyi, TOC, toprak besin düzenlemesi ve çıkan yabancı otları belirlemek için yapılmıştır. Orta (6.4g kg-1 toprak), yüksek (8 g kg-1 toprak) ve düşük (<3.9 g kg-1 toprak) TOC'de anlamlı ($p < .05$) tür zenginliği (Margalef indeksi) ve Shannon Weiner indeksi kaydedilmiştir. Yabancı ot türlerinin ortaya çıkışı, eğim boyunca SOC seviyesinden etkilenmiş ve kaynaktan gelen sonuçları temsil etmiştir. *Richardia scabra* gibi yabancı otların asidik kumlu topraklarda düşük SOC'ye bağlı olarak çıkışı olmuştur. Bununla birlikte, besin maddelerinin uygulanması (NPK+kireç tedavisi), yabancı ot türü sayısını 1.96±0.12'den 1.4±0.12'ye düşürmüştür. Sığır gübresi ve NPK+SG işlemleri, kontrolle karşılaştırıldığında önemli ölçüde daha yüksek yabancı ot çıkışı ve yabancı ot biyokütlesi kaydedilmiştir. Açıkça, sığır gübresi işlemleri toprak yabancı ot tohum bankasını önemli ölçüde arttırmaktadır; bu nedenle, sığır gübresi ile tedavi edilen tarlalarda çapa yoğunluğunun artması muhtemeldir.

Anahtar Kelimeler: Çimlenme, organik madde, toprak besin maddeleri, yabancı ot çeşitliliği, yabancı ot yönetimi

Received / Geliş Tarihi 12.01.2024
Accepted / Kabul Tarihi 25.04.2024
Publication Date / Yayın Tarihi 29.05.2024

Corresponding author / Sorumlu Yazar: Cosmas PARWADA
E-mail: cparwada@gmail.com

Cite this article as: Chipomho, J., Parwada, C., Mapope, N., & Simango, K. (2024). Effects of soil nutrient management on soil weed seed bank dynamics across a soil fertility gradient in smallholder farms, Eastern Zimbabwe. *Research in Agricultural Sciences,* 55(2), 105-114.

Introduction

Weeds are among the major constraints to crop production worldwide, especially among resource-constrained smallholders in sub-Saharan Africa (Mashingaidze et al., 2009). Weeds smother crops but more importantly, mature weed plants disperse and shed seeds into the soil, which ultimately accumulate and form soil weed seed banks (Schwartz-Lazaro & Copes, 2019). Weed seed banks consist of viable, dormant and non-dormant seeds; with potential to germinate and compete with crops, particularly at the delicate seedling stages (Lopes et al., 2020). Weed seed banks comprise of potentially germinable, and dormant weed seeds which are vertically, and horizontally distributed within the soil profile (Hussain et al., 2017). The number of weed seeds in the seed banks varies considerably depending on soil type and farmer's management practices *(Hussain et al.,* 2017); and knowledge of weed seed bank status is important for designing appropriate weed management strategies (Hussain et al., 2017).

Literature relating soil fertility to weed growth and proliferation is quite extensive, but overly contradictory (Moyo, 2005; Mtambanengwe et al., 2006; Nezomba et al., 2015). For instance, Mashingaidze et al. (2009) noted that high levels of soil fertility tend to reduce the competitive effect of weeds on crop growth and production. On the other hand, Schwartz-Lazaro & Copes (2019) concluded that low soil fertility affects the weeds as well as the crops. There are also varied reports that soil heterogeneity due to differences in inherent properties (organic matter, pH, aluminium toxicity, CEC, etc.) of the soil arising from different parent material, catena position and differences in the management practices within and across farms (Dessalegn et al., 2014; Nezomba et al., 2015). The catena influences micro-environment, the physical and chemical properties of this soil which also affect soil biological activities. This implies that soil fertility could be strategically leveraged in designing weed management programmes. However, the link between soil fertility and level and diversity of species in weed seed banks remains a subject for further investigation.

An estimated 70 % of smallholder farms in Zimbabwe are situated on low fertile soils (Chaumba et al., 2003; Moyo, 2005). In a bid to address low soil fertility challenges and improve maize productivity, resource-poor farmers use with limitations options available to them such as pit compost, anthill soils, livestock manures, crop residues and inorganic fertilisers (Mtambanengwe et al., 2006; Nyamangara et al., 2011). However, the use of livestock manure as a soil-improving organic amendment may increase weed density, and weed reproductive structures; for example, weed seed capsules thereby affecting the weed seed bank status. The objective of the study was to investigate short-term effect of SOC, and repeated soil nutrient amendment on weed seed bank emergence and biomass on smallholder farms across a soil fertility gradient on the catena.

Methods

Study site

Soil used in this study was obtained from three smallholder farms that were under short-term (six years) soil nutrient management in Wedza, (18°15' latitude, 32°22' longitude), Eastern Zimbabwe. The farms varied in SOC ((low= 3.9, medium= 6.4, high=8.9 g SOC kg^{-1} soil) and situated on the upper, middle and lower catena position, respectively. Soils in the three farms are generally infertility with low content of major nutrients N, P, K. The farms used in this study had similar previous land use practices (maize mono-cropping) under conventional tillage system. They were located in the natural region (NR) IIb, at an altitude of 1150 m above sea level, with a mean annual precipitation of >800 mm falling between November and March. The predominant soil type across the three farms was sandy textured soils derived from granitic parent material and classified as Alfisol (USDA soil taxonomy) or Lixisol (FAO soil classification).

Experimental design and sampling procedures

Soils for the weed seed bank studies were sampled from five treatments, namely, unfertilised control, 7%N, 14%P and 7%K (NPK), cattle manure (CM), NPK+CM and NPK+lime from each of the three farms (Zaka, Mwendamberi and Vengesai) along the catena. The smallholder farms had received fertiliser rates of 120 N, 26 P and 30 K kg ha^{-1}, while cattle manure applied treatments had received 5 t ha^{-1} in each season. Lime as a treatment was applied at 1.5 t ha^{-1} and this was done biannually; that is, 2011, 2013 and 2015. Treatments were laid out in a randomised complete block design.

From the three fields, six cores each with a diameter 15 cm were randomly collected each into a clean plastic bucket (10 litres), from a 0-20 cm plough depth. The sub-samples from each field were mixed into a composite sample. Seed bank sampling was done in 2014/15 and 2015/16 cropping seasons.

Weed diversity, emerged weeds and biomass

Soil samples of about 1000 g for each plot, were evenly spread (20 cm deep) in labelled germination trays and watered regularly (Forcella et al*.,* 2003). The weed emergence experiment was carried out in asbestos trays from mid-October in each season under green-house conditions.

Weed species were identified two weeks after weed seedling emergence and counted by specie (number kg^{-1}

soil). Biomass of emerged weeds in the entire plot were determined using a method described by Parwada et al. (2020). The emerged weed species were identified botanically, counted at approximately 2 cm in height. Then the weed species were cut at ground level, packed in khaki brown paper bags, and oven-dried for 48 hours at 70 °C for determination of emerged weed biomass (Forcella et al., 2003). This process was repeated once a week. In the seventh week after emergency, the soil in the trays was sun-dry for about five days. The soil on the trays was thoroughly and rewatered following the same routine, for an additional six weeks. At four weeks after emergency, diversity was determined using richness (Margalef index), evenness (Pie Lou index), (Pie Lou, 1966) and Shannon Weiner index (Shannon, 1948), *viz*:

$$\text{Shannon Wiener index (H)} = -\sum_{i-1}^{s} Pi\ In\ (Pi) \quad (1)$$

Where: H is Shannon Wiener diversity index, S is the number of individual species in the community (richness), Pi will be the proportion of S made up of the i-th species that is $p_i = N_i / N_{total}$, where N_i is the individuals of species i (plants m^{-2}) and N_{total} is the total number of individuals (plants m^{-2}).

Species Richness was determined based on the Margalef index:

$$R = \frac{S-1}{InN} \quad (2)$$

The community Evenness was determined using the Pie Lou's index:

$$J = \frac{H\prime}{InS} \quad (3)$$

Data analysis

Data on weed seed emergence and biomass of emerged weed seeds were tested for normality of variance using Ryne-Joiner and Bartlett's test, respectively. Analysis of variance was carried out by the Linear Mixed-Effects model Restricted Maximum Likelihood, in GenStat Discovery 14. Principal component analysis (PCA) was performed to establish relationships between season, SOC, soil nutrient amendment, and emerged weed seeds, using CANOCO 5).

Results

Weed diversity

Weed seed bank richness (Margalef index) and Shannon Weiner index were significantly influenced by levels of SOC (p < .001); but not evenness (Table 1). Margalef index increased in medium and high SOC content by 1.5 and 1.3 times, respectively; while the Shannon Weiner index increased by 1.3 and 1.1 times; compared to low SOC (Table 1). The farm nutrient application (NPK+CM) significantly (p < .001) increased Shannon Wiener index by 1.3 and Margalef index by 1.4 times compared to unfertilised control treatment (Table 1).

Table 1.

Effect of SOC and nutrient application on diversity indices (Margalef, Shannon Wiener and Pie Lou indexes) of weeds on-farm in Hwedza, Zimbabwe

	Weed diversity indices		
Parameter	Margalef index Richness	Shannon Wiener index	Pie Lou index Evenness
SOC content			
Low	1.44^a	1.47^a	0.62
Medium	2.10^c	1.84^c	0.65
High	1.87^b	1.68^b	0.60
F pr	<0.001	<0.001	Ns
SED	0.08	0.05	0.024
Soil nutrient amendments			
Control	1.54^a	1.52^a	0.69^d
NPK	1.64^b	1.60^a	0.62^c
NPK+LM	1.79^c	1.56^{ab}	0.60^a
CM	1.95^d	1.79^c	0.60^a
NPK+CM	2.11^e	1.86^c	0.61^b
F pr	<0.001	<0.001	0.011
SED	0.09	0.07	0.003
Interaction (SOC × soil nutrient amendment)			
F pr	0.014	0.003	Ns
SED	0.172	0.12	0.044

*Means followed by the same letter superscript in a column are no significantly different at p < .05.

The interaction of SOC level and soil nutrient application significantly (p < .05) affected species richness (Margalef) and Shannon Wiener Indices (Figures 1a and 1b); with the highest Margalef index recorded from the medium SOC compared to the other SOC contents. In the low and medium SOC levels, the lowest species richness was found in unfertilised control and NPK treatment. Co-application of NPK+CM and/or sole CM increased richness by 38.6 %, in the low SOC, and 45.5 % in the medium SOC levels. However, the Margalef index was not affected by the soil nutrient management in the high SOC content (Figure 1a).

Shannon Wiener index of less than 1.4 ± 0.12 was observed in unfertilised control, NPK, and NPK+LM; while significantly high Shannon indices (1.6 ± 0.12 and 1.7 ± 0.12) were recorded in treatments that received CM and NPK+CM, respectively under low SOC (Figure 1b). In contrast, in medium SOC, the Shannon index values increased 1.2 times in NPK, NPK+LM and 1.4 times in CM, NPK+CM. However, in high SOC, the Shannon index in NPK+LM was lower compared to other treatments (Figure 1b).

Weed seed bank numbers and biomass

Weed seedling emergence varied across the SOC statuses with values of 31.6 $\pm$ 0.73 and 29.2 $\pm$ 0.73 and 32.4 $\pm$ 0.73, corresponding to low, medium and high SOC, respectively (Figure 2a).

Total emerged weed seed bank numbers were significantly (p < .001) affected by soil nutrient management and SOC content along the catena (Fig. 2b).

Weeds seedling total biomass was also significantly (p < .001) affected by soil nutrient management and SOC levels (Table 1). The medium and high SOC contents had significantly higher weed biomass (5.97 $\pm$ 0.40 and 5.78 $\pm$ 0.40, respectively) compared to low SOC 4.14 $\pm$ 0.40 (Figure 2b).

Soil nutrient management markedly (p < .001) increased emerged total weed seed bank counts in NPK, NPK+CM, and CM by 3, 6 and 8 %, respectively compared to unfertilised control (Figure 3a). Weed seedling biomass from was also significantly (p < .001) increased by soil nutrient application; increasing by 67, 80, 166, and 200 % in NPK+LM, NPK, CM, and NPK+CM, respectively; compared to unfertilised control treatment (Figure 3b).

Soil Organic Carbon and weed seed bank species

The principal component analysis (PCA) recorded an association between SOC, season and weed seedling species composition (Figure 4). The PCA bi-plot accounted for 44.5 % of total variance in weed composition, with Axis 1 accounting for 28.1 % (eigenvalue of 0.281); while Axis 2 accounted for 16.4 % (eigenvalue =0.164). SOC content had a strong effect on weed seedling species composition. Weed seedling species were significantly (p < .05) linked to SOC levels according to position on the catena; thus, mimicking results from the original field experiment (Figure 4). However, the soil nutrient management was not significant (p < .05).

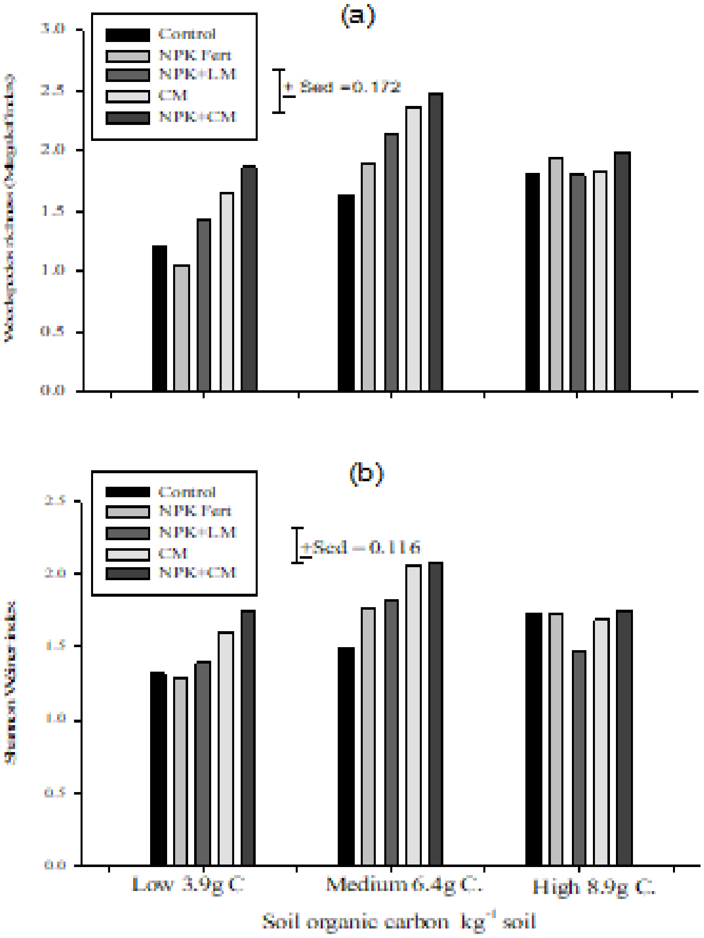

Figure. 1
Interaction of SOC × soil nutrient amendment on Margalef and Shannon Wiener indices.

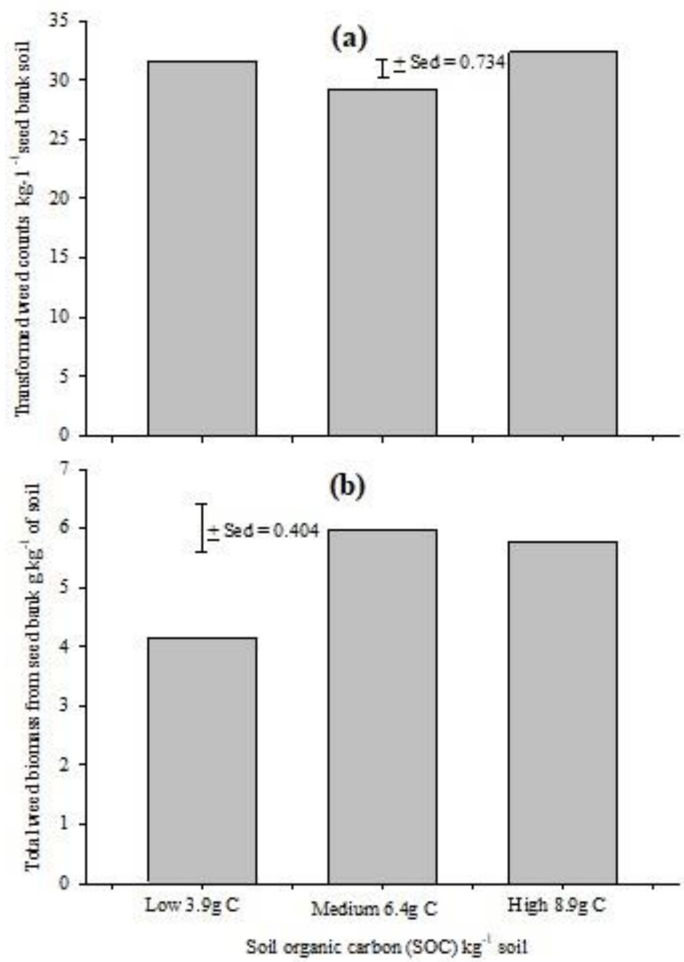

Figure 2.
Effect of SOC levels on weed seedling counts and biomass of during the 2014/15 and 2015/16 cropping seasons in Hwedza, Zimbabwe.

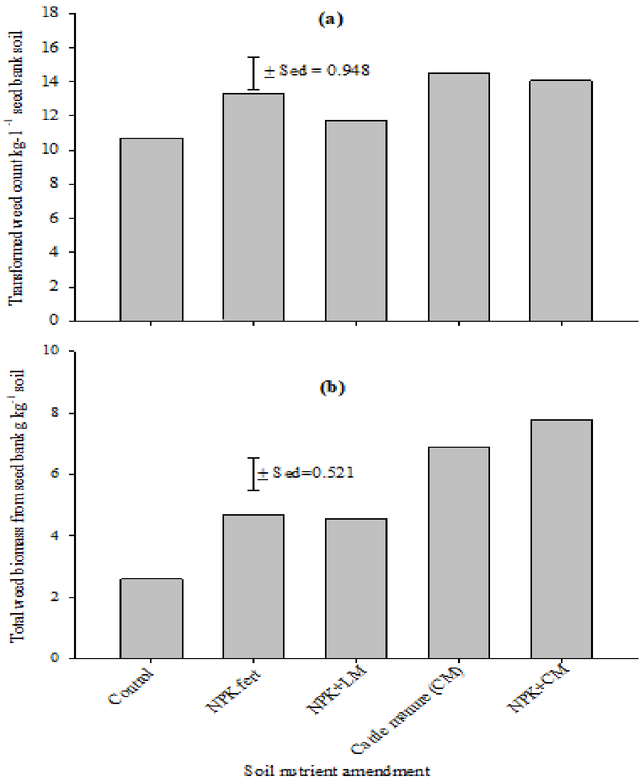

Figure 3.
Effect of soil nutrient management on weed seedling counts and biomass in 2014-2016) cropping seasons in Hwedza, Zimbabwe.

Weed seedling diversity and numbers varied markedly with season (Figure 5a). There was a spike in weed density in 2014 and 2015; then a decline in 2016 in high SOC content. In contrast, in the medium SOC levels, there was an increase in weed count in 2014; followed by a decline in 2015 and another increase in 2016 (Figure 5a).

The Principal Response Curves (PRCs) drawn from sampling season, SOC and their interactions was significant based on Monte Carlo permutation test (F= 30.2, p=.002). However, soil nutrient management was not significant ($p < .05$, Figure 5b). Weeds with positive weights on the PRC scale were *G. parviflora*, *D. stramonium*, *C. monophylla*, and *L. martinicensis;* while *R. scabra* and *S. pinnata* had negative weights (Figure 5b). The six species listed above were then further analysed using REML (Table 3). Seventy five percent of the weed species fell between -0.5 and 0.5 were not influenced by SOC content and were excluded from further analysis (Figure 5c).

The PRC showed that *C. monophylla*, *D. stramonium* and *G. parviflora* numbers increased with increase in SOC levels; while *R. scabra* and *S. pinnata* numbers decreased with increase in SOC (Table 2). Integration of NPK+CM increased the numbers of *D. stramonium* and *G. parviflora*; while sole NPK increased the counts of *R. scabra*. In contrast, *C. monophylla* and *S. pinnata* numbers were not affected by soil nutrient management (Table 2).

Table 2.
Principal Response Curve scale (PRC) of major seedbank weeds associated with affected by SOC content and nutrient amendments

	PRC weed species				
	C. monophylla	*D. stramonium*	*G. parviflora*	*R. scabra*	*S. pinnata*
SOC content (kg $^{-1}$ soil)					
Low	1.0^{a} (1)	1.9^{a} (6)	2.1^{a} (6)	5.5^{c} (28)	5.1^{c} (36)
Medium	2.3^{b} (9)	2.7^{b} (10)	2.3^{a} (6)	4.2^{b} (20)	3.0^{b} (17)
High	2.8^{c} (13)	4.1^{c} (21)	3.7^{b} (12)	2.7^{a} (7)	2.4^{a} (8)
F pr	<.001	<.001	<.001	<.001	<.001
SED	0.35	0.33	0.27	0.34	0.38
Soil nutrient amendments					
Control	2.1(9)	1.1^{a} (3)	1.6^{a} (3)	3.6^{b} (14)	2.8 (10)
NPK	1.8 (7)	2.1^{b} (9)	3.0^{c} (9)	5.2^{d} (26)	3.8 (25)
NPK+LM	1.9 (5)	1.6^{a} (3)	2.3^{b} (6)	2.1^{a} (7)	3.4 (21)
CM	2.4 (11)	4.7^{c} (21)	3.2^{cd} (10)	4.6^{c} (22)	3.5 (21)
NPK+CM	2.0 (5)	5.0^{c} (25)	3.4^{d} (12)	4.6^{c} (22)	4.0 (24)
F pr	Ns	<.001	<.001	<.001	Ns
SED	0.44	0.42	0.35	0.43	0.49

*****Means followed by the same letter superscript in a column are no significantly different at $p < .05$. †Numbers in brackets are back-transformed (actual) weed numbers m^{-2}.

Discussion

Diversity of weeds

Twenty-four weed species were identified from the soil seed bank study along a toposequence, indicating diverse weed species. An increase in Richness (Margalef index) and Shannon Weiner index was recorded in medium and high SOC content. The increase in weed diversity and weed community composition can be attributed to the effects of topography and nutrient management, on the across the toposequence. Topography steepness and orientation affect microclimate, determine water movement (infiltration, runoff, erosion, available moisture), deposition of nutrients, affect vegetation growth, radiation interception at different landscape positions (Boling et al., 2008; Kone et al., 2013). Boling et al. (2008) attributed the change in weed density along the catena to variation in soil texture, organic matter and macro-nutrient (NPK) content resulting from the above listed physical processes. The differences in texture, SOC and nutrient status along the catena also confirm the findings by Koné et al., (2013), who reported an increase in *Cyperus* density down the slope and attributed it to changes in soil physical and chemical properties along the catena.

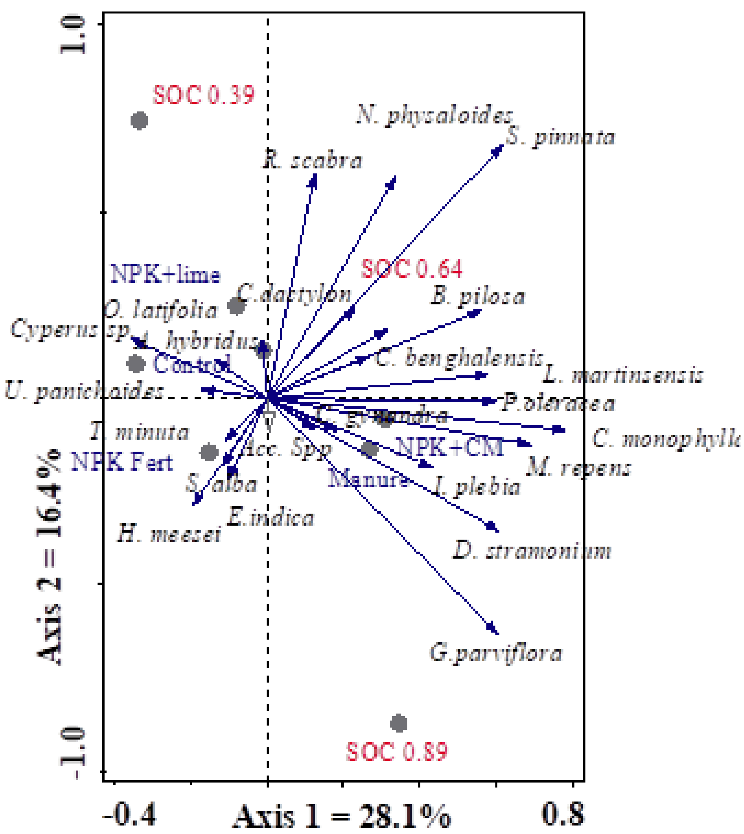

Figure 4.

Principal Component Analysis (PCA) Bi-plot projection of weed species for three seasons (2014-2016), affected by SOC content and soil nutrient management in Hwedza, Zimbabwe.

As depicted by soil characterisation of the experimental site, the upper catena consists of coarser soil texture with poor physical and chemical properties, compared to the lower catena (Boling et al., 2008). The sedimentation of fine-textured particles in the lower catena, according to Nezomba *et al*. (2015) increased clay content, iron oxides, pH and organic matter (OM), and may have resulted in a distinct fertility gradient from crest (upper) middle and lower (bottom) catena positions. The lower catena soil exhibits good physical and chemical properties for weeds establishment (Koné *et al*., 2013).

Weed species were strongly linked to SOC content along the soil catena (Fig. 6a). Weeds associated with sandy soils in the upper catena position appeared to be well adapted to infertile, low pH (acidophiles) and degraded soils (Mavunganidze *et al*., 2016). Weed species predominant in the middle and lower catena positions are known to have luxurious uptake of N and P and are referred to as nitrophilous and phosphophilous, respectively (Blackshaw *et al*., 2010) and pose a lot of competition in fertilised fields. The results confirm findings by Kone *et al*. (2013) and Touré et al. (2014) who reported physical spatial distribution of weeds along the catena as influenced by soil physical and chemical properties. Mavunganidze et al. (2016) also reported a strong association of weed species, soil texture and nutrient management.

Apart from variation in SOC content and location on the farm across the toposequence, nutrient management affected soil physical, chemical and biological properties and promoted nutrient uptake, water retention and improved soil health (Bera et al., 2018; Nezomba et al., 2015). Application of cattle manure (CM) and NPK+CM in low and medium SOC content increased species richness, Shannon Wiener, and Evenness. Soil fertility management, especially co-applying organic and in-organic fertilisers altered the composition and species diversity in farm fields (Table 2). The increased species diversity in NPK+CM suggested that balanced fertilisation improves or maintains soil stability and productivity. In contrast, Jiang et al. (2014) found that the application of organic fertilisers reduced the species number and richness index of the soil weed seed bank. These noted discrepancies could be due to difference in forage diets and mother plants content and diversity of weed species in each case.

Biomass of emerged weeds

Biomass of emerged weeds from soil samples increased by 7 % as the SOC content changed from 3.9 to 8.9 g kg^{-1} soil (Table 1). The inherently high SOC content, and optimum pH from medium and high SOC content could have stimulated the germination, and emergence of weed seeds (Tang et al., 2014). Moreover, the possible adequacy of nutrient and water supply to the emerged weeds, resulting from the treatments, could have caused rapid growth and therefore, boosted seedling biomass accumulation, which in turn could have translated into high weed reproductive capacity (Mavunganidze et al., 2009). Well-nourished weed plants tend to shed more weed seeds back into the seed bank, compared to their weak counterparts from low fertile upper catena (Koné et al., 2013).

The differences in weed biomass arising out of seed banks along the catena, have earlier been reported by several reserachers (Dessalegn et al., 2014; Koné et al., 2013; Malinowska and Szumacher, 2013; Touré et al., 2014). The increase in biomass from middle and lower catena is likely to be affected by the physical and chemical properties of the soils, which in turn affect nutrient and water uptake by the crop and weeds down the slope (Touré et al., 2014). Weeds tend to benefit more from inherent fertility, owing to their natural adaptation and greater ability to efficiently extract nutrient from such soils; these augment weed density and biomass (Wortman et al., 2011).

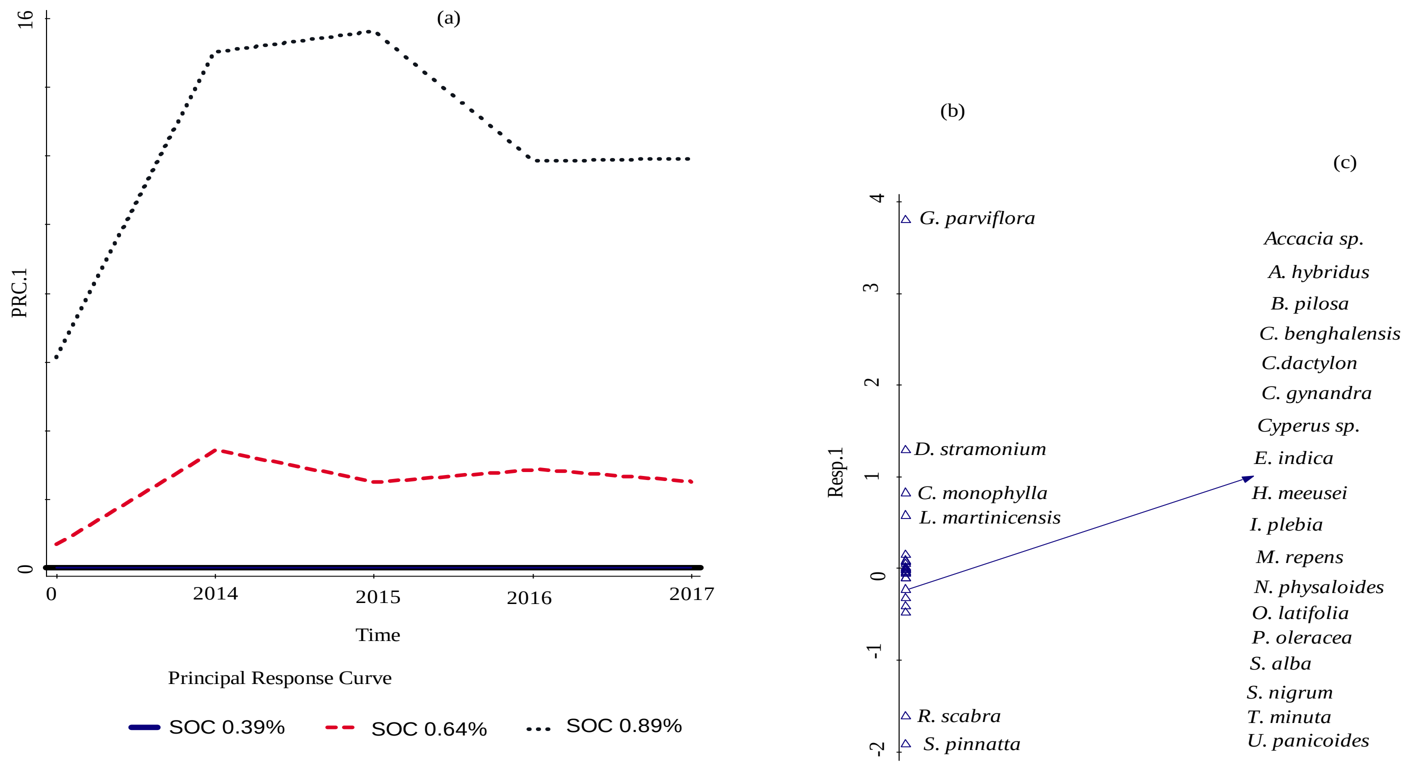

Figure 5

(a) Principal response curves (PRCs) on response of weed seed bank to SOC content. Medium and high SOC relative to standard low SOC over three sampling seasons (b) Principal response curve scale presentation on weed species strongly influenced by SOC status. (c)Weed species lying on –0.5 and 0.5 on the principal response curve scale and not considered for further analysis.

From the present study, NPK+CM and sole CM amended treatments increased weed seedling emergence from the soil by 6 and 8 %, respectively. *Datura stramonium, B. pilosa, A. hybridus*, *N. physaloides* and *G. parviflora* numbers were relatively high in these treatments and increased total biomass of emerged weeds as well. Application of livestock manure and fertiliser presumably benefit weeds through enhanced nutrition, breaking weed seed dormancy and initiation of weed seedling emergence (Karimmojeni et al. 2011), weed growth and competitiveness, weed biomass accumulation (Tang et al., 2014), and weed seed production (Blackshaw & Brandt, 2009).

Increased weed seedling numbers and biomass of treatments that received CM, NPK+CM was also attributed to cattle manure acting as a weed seed source or by providing possible stimulants for weed seed germination. This is a virgin area for future investigations. Otherwise, livestock manure is known to change physical (aggregation, aeration, infiltration, and water retention capacity) and chemical properties (cation exchange capacity, amelioration of soil pH) of the soil (Wortman *et al*., 2010; Kone et al., 2013). This has been found to benefit crops and also un-intentionally benefits weeds (Chipomho et al., 2018). Furthermore, cattle manure is known to carry enormous numbers of germinable weed seeds (Materechera & Modiakgotla, 2006) and this is associated with high density and biomass in field crops, especially when the soil has not been cured or incubated for less than five months. Rupende et al. (1998) observed that *A. hybridus*, *E. indica* and *N. physaloides* densities were associated with cattle manure which was treated for less than four weeks. Results from our study suggested that manure use in agro-ecosystems is a potential source weed seeds into the soil seed banks (Smith et al., 2008). Generally, the application of CM, NPK+CM, and NPK+lime ameliorates soil pH and increases nutrient uptake by weeds, thereby increasing weed numbers and biomass of emerged weeds from seedbank compared to the control treatment. Blackshaw et al. (2010) concluded that the use of organic and inorganic fertilisers does not only benefit the crop but weeds as well.

Conclusion and Recommendations

This study has demonstrated the effect of soil fertility management on weed species emergence from a weed seed bank, diversity, numbers and biomass across a SOC gradient of a cultivated catena in Zimbabwe. *Melinis repens*, *R. scabra*, *Cyperus* sp. and *S. pinnata* weed species were associated with low SOC content on upper catena position; while *B. pilosa*, *N. physaloides*, *L. martinicensis*, *C. monophylla*, *D. stramonium*, *H. meeusei* and *G. parviflora* were strongly linked to medium and high SOC content on middle and lower catena positions. Generally, livestock manure treatments were associated with the greatest seedling emergence, weed biomass and species diversity. Thus, manure can be external major source of weed seed, unless when pre-treated prior to its application. However, the mode of contribution of cattle manure to the weed seed bank, which may be by harbouring weed seeds, providing germination stimulants, enhancing weed nutrition or providing a more favourable growth environment, requires further investigation.

Peer-review: Externally peer-reviewed.
Author Contributions: Concept -J.C., C.P; Design- C.P., N.M., J.C; Supervision- J.C; Resources- K.S; Data Collection and/or Processing-K.S., J.C; Analysis and/or Interpretation-C.P., N.M; Literature Search-N.M., JC., C.P., K.S; Writing Manuscript-J.C., N.M., C.P; Critical Review-C.P., J.C
Conflict of Interest: The authors have no conflicts of interest to declare.
Financial Disclosure: The authors declared that this study has received no financial support.

Hakem Değerlendirmesi: Dış bağımsız.
Yazar Katkıları: Konsept -J.C., C.P; Tasarım-C.P., N.M., J.C; Denetleme-J.C; Kaynaklar-K.S; Veri Toplanması ve/veya İşlemesi-K.S., J.C; Analiz ve/veya Yorum-C.P., N.M; Literatür Taraması-N.M., JC., C.P., K.S; Yazıyı Yazan-J.C., N.M., C.P; Eleştirel İnceleme-C.P., J.C.
Çıkar Çatışması: Yazarlar, çıkar çatışması olmadığını beyan etmiştir.
Finansal Destek: Yazarlar, bu çalışma için finansal destek almadığını beyan etmiştir.

References

Blackshaw, E., Brandt, N. & Janzen, H. (2002). Weeds dine out on nitrogen and phosphorus. *Better Crops with Plant Food,* 86(1), 20–22.

Blackshaw, R.E. (2005). Nitrogen fertilizer, manure, and compost effects on weed growth and competition with spring wheat. *Agronomy Journal,* 97(6), 1612–1621. https,//doi.org/10.2134/agronj2005.0155

Blackshaw, E. & Brandt, N. (2009). Phosphorus fertilizer effects on the competition between wheat and several weed species. *Weed Biology and Management,* 9(1), 46–53.

Boling, A., Tuong, P., Suganda, H., Konboon, Y., Harnpichitvitaya, D., Bouman, M. & Franco T. (2008). The effect of toposequence position on soil properties, hydrology and yield of rain-fed lowland rice in Southeast Asia. *Field Crops Research,* 106,22–33.

Cavers, P.B. & Benoit, D.L. (1989). Seed banks in arable lands. In MA. Leck, VT. Parker, and RL. Simpson (eds.) Ecology of soil seed banks.

Chaumba, J., Scoones, I. & Wolmer, W. (2003). From Jambanja to Planning: The Reassertion of Technocracy in Land Reform in South-Eastern Zimbabwe? *The Journal of Modern African Studies,* 41, 533–554. https://doi.org/10.1017/S0022278X03004397

Chikoye, D., Manyong, V.M. & Ekeleme, F. (2000). Characteristics of spear grass (*Imperata cylindrica*) dominated fields in West Africa: Crops, soil properties, farmer perceptions, and management strategies. *Crop Protection,* 19, 481–487. https://doi.org/10.1016/S0261-2194(00)00044-2

Chipomho, J., Masuka, B.P., Chabata, M.M., Chipomho, C. & Msindo, B. (2018). Organic soil amendments: Implications on fresh tomato (*Solanum lycopesicum*) yield, weed density, and biomass. *Journal of Animal and Plant Science,* 28(3), 845–853.

Chitigu, B., Rugare, J.T. & Mabasa, S. (2013). Screening Maize (*Zea mays)* Genotypes for Tolerance to witch weed (Striga Screening Maize (*Zea mays*) Genotypes for Tolerance to witch weed (*Striga asiatica* L. Kuntze) Infection. *Journal of Agricultural Science,* 6(2), 160–169. https://doi.org/10.5539/jas.v6n2p160

Chivenge, P., Vanlauwe, B. & Six, J. (2011). Does the combined application of organic and mineral nutrient sources influence maize productivity? A meta-analysis. *Plant Soil,* 16, 1–30. https://doi.org/10.1007/s11104-010-0626-5

Conn J.S. (2006). Weed seed bank affected by tillage intensity for barley in Alaska. *Soil and Tillage Research,* 90, 156–161.

Creech, J.E., Westphal, A., Ferris, V.R., Faghihi, J., Vyn, T.J., Santini, J.B. & Johnson, W.G. (2008). Influence of winter annual weed management and crop rotation on soybean cyst nematode (*Heterodera glycines*) and winter annual weeds. *Weed Science,* 56, 103–111.

Davis, A.S., Renner, K.A. & Gross, K.L. (2005). Weed seed bank and community shifts in a long-term cropping system experiment. *Weed Science,* 53(3), 296–306. https://doi.org/10.1614/ws-04-182

Dvorsky, M., Dolezal, J., de Bello, F., Klimesova, J. & Klimes, L. (2011). Vegetation types of East Ladakh: species and growth form composition along main environmental gradients. *Applied Vegetation Science,* 14, 132–147.

Forcella, F. (2003). Debiting the seedbank: Priorities and predictions. In Bekker *et al*. (eds.) Seedbanks: Determination, dynamics and management. Aspects of Applied Biology, 69. Association of Applied Biologists, Welles Bourne, UK. pp. 151–162.

Fried, G., Petit, S. & Dessaint, F. (2009). Arable weed decline in Northern France: crop edges as refugia for weed conservation? *Biological Conservation,* 142, 238–43.

Hammer, O., Harper, D.A.T. & Paul, D.R. (2001). Past:

paleontological statistics software package for education and data analysis. *Palaeontol. Electron,* 4, 1–9.

Hussain, M., Safdar Ali, S., Muhammad Naveed Tahir, MN., Ghulam Abbas Shah, GA., Ijaz Ahmad, I., Muhammad Aqeel Sarwar, M.A. & Sohail Latif, S. (2016). Comparative Study of Soil Weed Seed Bank Determination in Pothwar Region by using Different Methodologies. *Agronomy Research,* 14(4), 1372–1379.

James, T.K., Rahman, A. & Mellsop, J. (2000). Weed competition in maize crop under different timings for post-emergence. *Weed Control,* 6, 269–272.

Jiang, M., Shen, X.P., Gao, W., Shen, M.X. and Dai, Q.G. (2014). Weed seed-bank responses to long- term fertilization in a rice-wheat rotation system. *Plant Soil Environment,* 60(8),344-350.

Karimmojeni, H., Taab, A., Rashidim, B. & Bazrafshan, A. (2014). Dormancy breaking and seed germination of the annual weeds Thlaspi arvense, Descurainia sophia and Malcolmia africana (Brassicaceae). *Journal of Plant Protection Research,* 54(2). https://doi.org/10.2478/jppr-2014-0028

Kent, R. J. & Johnson, D.E. (2001). Influence of flood depth and duration on the growth of lowland rice weeds, Côte d'Ivoire. *Crop Protection,* 20, 691–694.

Kone, B., Amadji, G.L., Touré, A., Togola, A., Mariko, M. & Huat, J. (2013). A Case of *Cyperus sp*. and *Imperata cylindrica* occurrences on Acrisol of the Dahomey gap in South Benin as affected by soil characteristics: A Strategy for soil and weed management. *Applied and Environmental Soil Science,* http://dx.doi.org/10.1155/2013/601058

Koné, B., Touré, A., Amadji, G. L., Yao-Kouamé, A., Angui, P. T. & Huat, J. (2013). Soil characteristics and *cyperus spp*. occurrence along a toposequence. *African Journal of Ecology,* 51(3), 402–408. https://doi.org/10.1111/aje.12050.

Kurwakumire, N., Chikowo, R., Mtambanengwe, F., Mapfumo, P., Snapp, S., Johnston, A. & Zingore, S. (2014). Maize productivity and nutrient and water use efficiencies across soil fertility domains on smallholder farms in Zimbabwe. *Field Crops Research,* 164(1), 136–147. https://doi.org/10.1016/j.fcr.2014.05.01

Lee, N. & Thierfelder, C. (2017). Weed control under conservation agriculture in dryland smallholder farming systems of Southern Africa. A review. *Agronomy for Sustainable Development,* 37, 48-56.

Li, K., Fan, H., Yin, P., Yang, L., Xue, Q., Li, X., Sun, L & Liu, Y. (2017). Structure-activity relationship of eight high content flavonoids analysed with a preliminary assign-score method and their contribution to antioxidant ability of flavonoids-rich extract from *Scutellaria baicalensis* shoots. *Arabian Journal of Chemistry,* 11(2), 159-170.

Louren, M., Schwartz-Lazaro, S & Josh T. C. (2019). A Review of the Soil Seedbank from a Weed Scientists Perspective. *Agronomy,* 9, 369. https://doi.org/10.3390/agronomy907036

Mashingaidze, A.B., Van Der Werf, W., Lotz, L.A.P., Chipomho, J., & Kropff, M.J. (2009). Narrow rows reduce biomass and seed production of weeds and increase maize yield. *Annals of Applied Biology,* 155(2), 207–218.

Masvaya, E.N., Nyamangara, J., Nyawasha, R.W., Zingore, S., Delve, R.J. & Giller, K.E. (2010). Effect of farmer management strategies on spatial variability of soil fertility and crop nutrient uptake in contrasting agro-ecological zones in Zimbabwe. *Nutrient Cycling in Agroecosystems,* 88(1), 111–120. https://doi.org/10.1007/s10705-009-9262-y

Materechera, S.A. & Modiakgotla, L.N. (2006). Cattle manure increases soil weed population and species diversity in a semi-arid environment. *South African Journal of Plant and Soil,* 23 (1), 37–41. https://doi.org/10.1080/02571862.2006.10634725

Mavunganidze, Z., Madakadze, I. C., Nyamangara, J. & Mafongoya, P. (2016). Influence of selected soil properties, soil management practices and socio-economic variables on relative weed density in a hand hoe-based conservation agriculture system. S*oil Use and Management* 28, 1–13. https://doi.org/10.1111/sum.12287

Moyo, S. (2005). Land Redistribution and Public Action in Zimbabwe. *African and Asian Studies,* 4, 187–223.

Mtambanengwe, F. & Mapfumo, P. (2006). Effects of organic resource quality on soil profile N dynamics and maize yields on sandy soils in Zimbabwe. *Plant and Soil,* 281(1–2), 173–191. https://doi.org/10.1007/s11104-005-4182-3

Nezomba, H., Mtambanengwe, F., Tittonell, P. & Mapfumo, P. (2015). Point of no return? Rehabilitating degraded soils for increased crop productivity on smallholder farms in eastern Zimbabwe. *Geoderma,* 239, 143–155. https://doi.org/10.1016/j.geoderma.2014.10.00

Parwada, C., Chigiya, V., Ngezimana, W. & Chipomho, J. (2020). Growth and performance of baby spinach (*Spinacia oleraceae* L.) grown under different Organic Fertilizers. *International Journal of Agronomy,* https://doi.org/10.1155/2020/8843906

Pielou, E.C. (1966). The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology,* 13, 131–144.

Rupende, E., Chivinge, O.A. & Mariga, I.K. (1998). The effect of storage time on weed seedling emergence and nutrient release in cattle manure. *Experimental*

Agriculture, 34, 277-285.

Rusinamhodzi, L., Corbeels, M., Zingore, S., Nyamangara, J. & Giller, K. E. (2013). Pushing the envelope? Maize production intensification and the role of cattle manure in recovery of degraded soils in smallholder farming areas of Zimbabwe. *Field Crops Research,* 147, 40–53. https://doi.org/10.1016/j.fcr.2013.03.014

Shannon, C.E. (1948). A mathematical theory of communication. *Bell System Technical Journal,* 27, 379–423.

Simpson, E.H. (1949). Measurement of diversity. N*ature* 163: 688.

Smilauer, P. & Lepš, J. (2014). Multivariate Analysis of Ecological Data Using CANOCO 5. Cambridge University Press. pp 58-64.

Steel, R.G.D., Torrie, J.H. & Dicky, D.A. (1997). Principles and procedures of statistics. A biometry approaches. 3rd edition MacGraw-Hill, New York. 352–358.

Tang, L., Wan, K., Cheng, C., Li, R., Wang, D., Pan, J., Tao, Y., Xie, J. & Chen, F. (2014). Effect of fertilization patterns on the assemblage of weed communities in an upland winter wheat field. *Journal of Plant Ecology,* 7(1), 39–50.

Tibugari, H., Chikasha, T., Manyeruke, N., Mathema, N., Musara, J.P., Dlamini, D., Mapuranga, R., Mapanje, O., Banda, A. & Parwada, C. (2019). Poor maize productivity in Zimbabwe: Can collusion in pricing by seed houses be the cause? *Cogent Food and Agriculture,* 5, 1682230 https://doi.org/10.1080/23311932.2019.1682230

Touré, A., Rodenburg, J., Marnotte, P., Dieng, I. & Huat, J. (2014). Identifying the problem weeds of rice-based systems along the inland-valley catena in the southern Guinea Savanna, Africa. *Weed Biology and Management,* 14 (2), 121-132. https://doi.org/10.1111/wbm.12040

Vanlauwe, B.A., Chianu, J.A., Giller, K.E.B., Merckx, R.C., Mokwunye, U.D., Pypers, P.A. & Shepherd, K.E. (2010). Integrated soil fertility management: operational definition and consequences for implementation and dissemination. *Outlook on Agriculture,* 10 (64-79), 194–197. https://doi.org/10.5367/000000010791169998

Whitehouse, M.E.A., Wilson, L.J., Davies, A.P., Cross, D., Goldsmith, P., Thompson, A., Harden, S. & Baker, G. (2014). Terget and non-Terget effects of novel “triple-stacked” Bt transgenic cotton 1: canopy arthropod communities. *Environment Entomology,* 43, 218–241.