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Research Article

Effect of Intercropping and Mulching on Weed Composition in Agroclimatic Zones of Zimbabwe

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Weed species composition is significantly affected by crop management practices. Intensive cropping is often associated with a reduction in weed species diversity. This study was conducted to assess the effect of intercropping and mulching on weed flora in three agroecological regions in eastern Zimbabwe. Two replicated on-farm trials were laid out in three agroecological regions. Treatments included sole maize, sole maize with 4 or 8 $\mathrm{Mg\,ha^{-1}}$ mulch, sole cowpea, maize + cowpea intercrop and maize + cowpea intercrop with 4 or 8 $\mathrm{Mg\,ha^{-1}}$ mulch. Maize stover was used as mulch. Different weeds were identified and sampled at five positions within plots using 0.5 m × 0.5 m quadrats. Among the 34 weed species identified across sites, *Richardia scabra* and *Cynodon dactylon* were the most dominant weed species and were mostly associated with sole maize cropping. Maize stover as mulch contributed to a reduction in weed species density. Maize + cowpea intercropping systems proved effective particularly in suppressing the prevalence of *R. scabra* and *C. dactylon*. Cowpea grown as a sole crop was found to be effective in reducing the infestation of weeds. Maize intercropped with cowpea along with mulching resulted in a significant reduction of weed species, especially in arid agroecological zones.

Keywords: *Cynodon dactylon*; intercropping; mulching; *Richardia scabra*; weed flora

1. Introduction

Weeds are a major biological challenge that seriously threatens crop production worldwide [1]. Weeds impose competition for nutrients, solar radiation and water; they set in at early crop growth stages; and their relative density plays a significant role in reducing yield and quality of the crop [2]. Severe weed infestation significantly contribute to yield losses among smallholder farmers in sub-Saharan Africa (SSA), largely due to limited weed control strategies and a lack of diverse cropping systems [3]. As regards the various weed control measures, manual eradication has proved superiority over all the measures in managing weeds. However, adoption of this technique has not gained popularity as it is time-consuming, labour-intensive and many times becomes impractical because of scarcity of labour during peak labour periods [4, 5]. Consequently, timely weed control becomes impossible because of labour scarcity which results in conducive conditions for season long severe weed competition [6]. Under such conditions, weed species dominate the cropping system and interfere with the resource use efficiency of nutrients, radiation and soil moisture, ultimately affecting crop productivity [7]. Moreover, cropping systems adopted by farmers significantly affect the composition and spatial distribution of weeds. However, the majority of smallholder farmers in SSA predominantly practice sole cropping of maize (*Zea mays* L.) [8, 9]. Sole cropping of maize is not viable as it has led to infestation of weeds which make weed management problematic [7].

Maintaining specific crop management practices within specified environmental conditions strongly drives temporal and spatial weed species distribution [10]. Weed adaptation to specific crop management systems allows for specific traits for survival which ultimately determine survival of weed species within an agroecosystem [11]. Specific weed species can easily adapt, and others are not able to survive [12]. For instance, continuous maize cultivation increases susceptibility to parasitism by the weed *Striga asiatica* L. Kuntze [13]. When specific weeds dominate cropping systems, they become difficult to control, creating need for alternative cropping systems and weed control methods that disrupt crop–weed interactions. Diversifying cropping systems leads to significant changes in weed community composition and structure [14]. Abbas et al. [15] reported that maize + gram (*Vigna radiata* L.) intercropping is effective in reducing *Echinochloa colona* (L.) and *Trianthema portulacastrum* L. as compared to sole maize. Paddy straw mulch was found to be effective in reducing the density of *Cyperus rotundus* and *Trianthema portulacastrum* [16]. Therefore, intercropping and legumes between maize rows have been found quite effective in weed suppression. Intercropping provides enough opportunity to control weeds while posing no damage to the environment. Intercropping, particularly cereal + legume combinations, boosts productivity by using resources better. However, mulch can effectively suppress weed growth by creating a physical barrier to weed emergence and germination by reducing light penetration to the soil surface [11, 17].

Thus, intercropping and mulching can be effective strategies for weed control, leading to reduced weed biomass and improved crop yields. Keeping the above facts in view, the experiment was conducted to assess the effect of intercropping and mulch on weed flora in three agroecological regions (AERs) of eastern Zimbabwe.

2. Materials and Methods

2.1. Study Site. A field experiment was conducted at different locations, viz. Murehwa and Mutoko, which are in Mashonaland East, a province located in the north-eastern part of Zimbabwe (Figure 1). Murehwa is characterised by subtropical conditions and lies in agroecological region IIb (AER 2b), which receives 700–1050 mm of annual rainfall. On the other hand, Mutoko district is characterised by two AERs, namely agroecological region III (AER 3) and agroecological region IV (AER 4), which are characterised by subtropical and semiarid conditions, respectively. AER 3 receives 500–800 mm, and AER 4 receives 450–650 mm per annum rainfall in a single season. The soil of the two experimental sites was of different textures (sandy and clay).

The predominant crop grown in the study sites is maize. Traditional crops such as sorghum and legumes such as groundnut and cowpea are also grown on the remaining farm area. All the AERs receive rainfall in a unimodal pattern. Meter Environment ZL6 weather stations located in each of the AERs were used to record rainfall. Total rainfall in the crop growing season recorded during the first year of cropping remained substantially higher compared to the second year (Figure 2). This was due to an extended mid-season dry spell in all the regions between January and February, which was brought about by the El Nino-induced drought.

2.2. Experimental Design. The experiment was laid out in randomised complete block design (RCBD) and replicated thrice. Table 1 shows the different treatments that were used in this study. Treatments are comprised of sole maize, no mulch (control), sole maize + 4 Mg ha^{-1} low mulch rate (LM), sole maize + 8 Mg ha^{-1} high mulch rate (HM), sole cowpea without mulch, maize + cowpea intercrop without mulch, maize + cowpea intercrop + 4 Mg ha^{-1} mulch and maize + cowpea intercrop + 8 Mg ha^{-1}. Maize stover from the previous season was used as mulch because of its widespread availability on smallholder farms, where it serves as feed for livestock during the dry season. The mulch rates were selected based on the recommendation reported by Lee and Thierfelder [18]. The 4 Mg ha^{-1} mulch rate reflects a feasible input level for smallholder farmers, aligning with typical residue availability and labour constraints. In contrast, the 8 Mg ha^{-1} mulch rate represents a treatment that effectively enhanced ground cover.

2.3. Experiment Management. A field experiment was laid out during the 2022/23 and 2023/24 cropping seasons. We applied the recommended basal fertiliser at 21, 18 and 35 kg ha^{-1} NPK, respectively, using a commonly used compound fertiliser (7% N: 14% P_2O_5: 7% K_2O). Moreover, topdressing 69 kg N ha^{-1} was applied at four and 6 weeks after sowing using ammonium nitrate (AN). Maize variety SC 555 was sown at a spacing of 0.9 m × 0.3 m for both sole and intercropping systems to achieve a plant population of 37,000 plant ha^{-1}. Cowpea variety CBC 2 was sown between maize rows with 0.15 m as intrarow spacing to achieve plant population of 74,000 plants ha^{-1} and as sole cowpea was sown at a spacing 0.45 m × 0.15 m to achieve plant population of 148,000 plants ha^{-1}.

2.4. Weed Sampling. Weed sampling was conducted by randomly placing quadrats measuring 0.5 m × 0.5 m at five positions forming a 'W' pattern [19]. Weeds within the quadrats were identified, counted and recorded according to species. Weed density was expressed as the total number of weed species m^{-2} in the different treatments. Relative weed density of each weed species was calculated using the formula adopted from [20]:

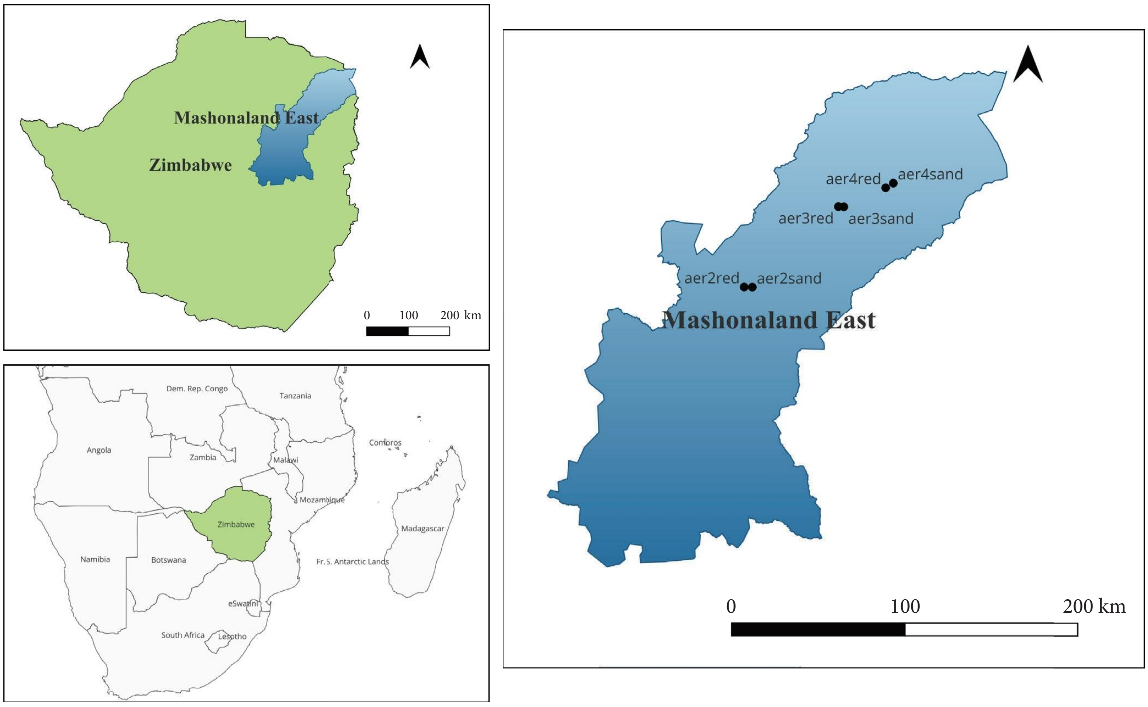


Figure 1: Study map showing the locations of six on-farm trials on red clay and sandy soils in Mashonaland East, Zimbabwe.

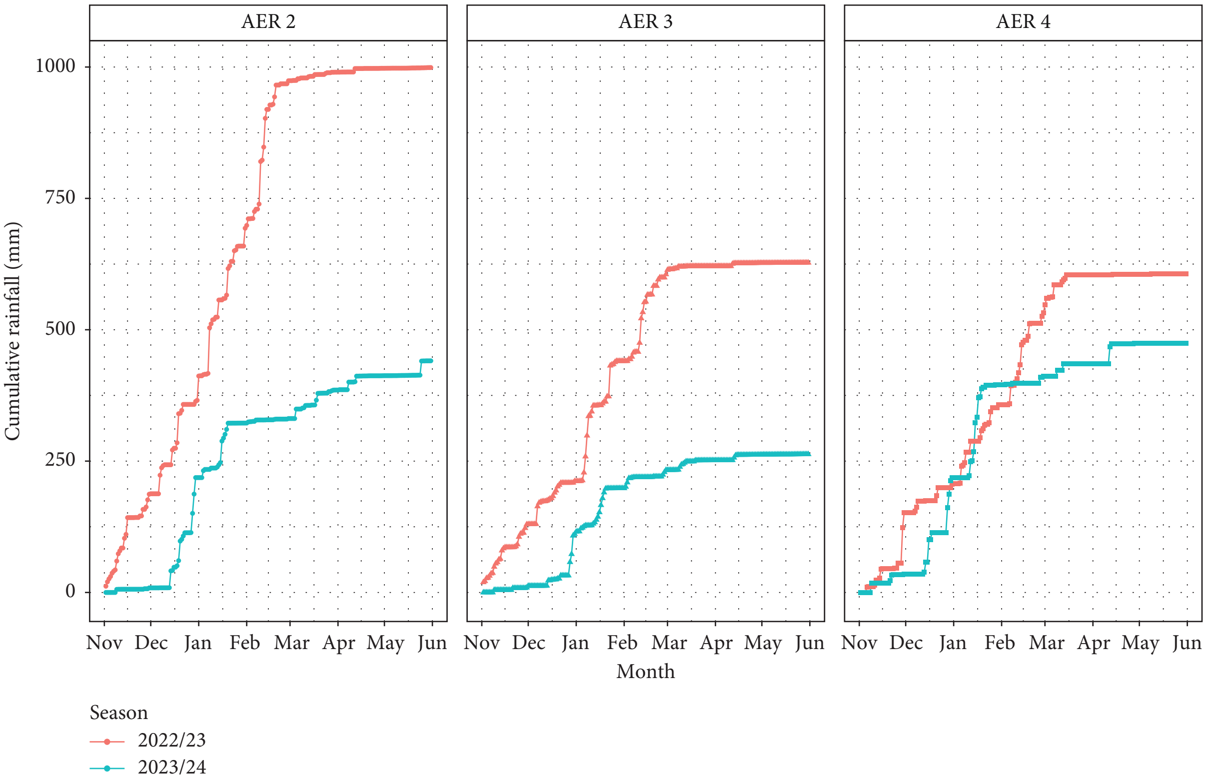


Figure 2: Cumulative rainfall in different agroecological regions (AERs) during the crop growing seasons.

$$\text{Relative weed density} = \left(\frac{\text{density of individual weed species}}{\text{weed density}}\right) \times 100\%. \tag{1}$$

Table 1: Intercropping and mulch description in agroecological regions IIb, III and IV on contrasting soils during the 2022/23 and 2023/24 crop growing seasons.

Treatment code	Treatment description
M	Sole maize, no mulch (control)
MLM	Sole maize + 4 Mg ha^{-1} low mulch rate (LM)
MHM	Sole maize + 8 Mg ha^{-1} high mulch rate (HM)
C	Sole cowpea, no mulch
MC	Maize + cowpea intercrop, no mulch
MCLM	Maize + cowpea intercrop + 4 Mg ha^{-1} mulch
MCHM	Maize + cowpea intercrop + 8 Mg ha^{-1}

2.5. Data Analysis. Statistical analyses were performed using R software package, Version 4.4.3. Prior to analysis, data were checked for normality using visual inspections (quantile–quantile plots and density distributions). Linear models were fitted using the *lm ()* function from the *stats* package. An analysis of variance (ANOVA) was then conducted on the models. Separation of means was done using the Tukey post hoc test at 0.05 probability using the *emmeans* package [21]. AERs and soil types were separately assessed to investigate their effects on weed flora. Cluster heatmaps were generated using *pheatmap* package to visualise weed patterns and relationships in the treatments.

3. Results

3.1. Weed Occurrence. A total of 34 weed species belonging to 18 families were observed throughout the cropping period (Table 2). Among the 18 families, Poaceae and Asteraceae emerged as the most dominant, contributing 32%. The weeds that were observed in experimental sites were predominantly annual species. The most abundant weed species were broadleaved weeds (76.5%), followed by grasses (17.7%) and sedges (5.9%). Therophytes were the most dominant plant lifeform of all the weeds identified with 55.9%, followed by Hemicryptophytes (29%), Chamaephytes (8.8%), Phanerophytes (2.9%) and Cryptophytes (2.9%). Hemicryptophytes and therophytes were the most common plant life forms among the dominant weed species (Table 3). Across the agroclimatic gradient, the highest number of individual weed species was observed in AER 3 (30 species), followed by AER 4 (28 species), and the lowest AER 2 (24 species). There were 17 weed species that were common in all the AERs.

3.2. Weed Prevalence. Weed species with an average relative weed density of 3%, namely *Richardia scabra*, *Cynodon dactylon*, *Fimbristylis exilis*, *Bidens pilosa*, *Acanthospermum hispidum*, *Cyperus esculentus*, *Digitaria ternata* and *Leucas martinicensis*, were considered to be the most dominant species (Table 3). Among 34 weed species observed, *R. scabra* was the dominant weed species. This weed was dominant in all treatments during the entire cropping period except in maize + cowpea intercropping without mulch, where *C. dactylon* was the dominant weed species. Overall, *C. dactylon* was the second most dominant weed in all the treatments. Maize + cowpea intercropping without mulch, maize + cowpea intercropping with 4 Mg ha^{-1} and sole cowpea recorded higher *C. dactylon* density than sole maize. Sole maize with mulch and maize + cowpea intercropping with 8 Mg ha^{-1} mulch significantly reduced *C. dactylon* density compared to sole maize. *F. exilis* was observed to be the third dominant weed species. During the 2022/23 season, *F. exilis* density in sole maize with either LM or HM rate was lower than sole maize without mulch. In contrast, sole cowpea and maize + cowpea intercropping with mulch at both application rates increased *F. exilis* density compared with the sole maize. All treatments with mulching, intercropping and sole cowpea reduced *F. exilis* density in 2023/24 season, while sole maize recorded the highest density. *B. pilosa* was the fourth dominant weed species in this study, and its density was lower in sole maize compared to maize + cowpea intercropping during the first crop growing season.

During the 2023–24 cropping season, sole maize with 8 Mg ha^{-1}, maize + cowpea intercropping without mulch and sole cowpea reduced *B. pilosa* density. The fifth dominant weed, *A. hispidum*, was not influenced by intercropping and mulching throughout the cropping period. Sole maize without mulch recorded the lowest density of *A. hispidum* among other treatments of intercropping and mulching. *Cyperus esculentus* was observed to be the sixth dominant weed species. The density of the weed was reduced in all treatments during both cropping seasons except in maize + cowpea intercropping with 8 Mg ha^{-1} mulch during the 2022–23 cropping season. This weed species was followed by *D. ternata* as the seventh dominant weed, and during the cropping season of 2022–23, *D. ternata* density was higher in both sole maize and maize + cowpea intercropping with 8 Mg ha^{-1} mulch and sole cowpea compared with sole maize. The last dominant weed species identified in this study was *L. martinicensis*. Maize + cowpea intercrop without or with both mulch rates and sole cowpea suppressed *L. martinicensis* comparing with sole maize with or without mulch in the 2022–23 season. However, during 2023–24 cropping season, intercropping systems and mulching suppressed *L. martinicensis* density and sole maize recorded the highest density. Moreover, two obligate root parasitic weeds, namely *S. asiatica* and *Alectra vogelii*, were also observed as 10th and 32nd weeds (Table 3). Application of mulch in sole maize reduced *S. asiatica* density; however, maize + cowpea intercropping together with mulching was found to be effective in the suppression of this weed. *Alectra vogelii*, which is parasitic to cowpea, was suppressed by maize + cowpea intercropping with and without mulch, and density was highest in sole cowpea. This suppression was dependent on the mulch application rate, where maize + cowpea intercropping with 8 Mg ha^{-1} recorded the lowest density (Table 3).

3.3. Effect of Intercropping and Mulch on Weed Flora. In AER 2 on red soils, sole maize recorded highest densities of individual weed species including *C. dactylon*, *B. pilosa* and *R. scabra* (Figure 3(a)). *Cynodon dactylon* in sole maize without mulch was identified as the dominant weed species

Table 2: Occurrence of weed species identified in three agroecological regions of north-eastern Zimbabwe.

Family	Scientific name	Classification	Raunkiær life form	AER 2	AER 3	AER 4
Amaranthaceae	*Amaranthus hybridus* L.	AB	Therophyte	●	○	○
Asteraceae	*Bidens pilosa* L.	AB	Therophyte	●	○	●
	Acanthospermum hispidum D.C.	AB	Therophyte	●	●	●
	Tagetes minuta L.	AB	Therophyte	●	●	●
	Tridax procumbens L.	AB	Therophyte	○	●	●
	Galinsoga parviflora Cav.	AB	Therophyte	●	○	●
Caryophyllaceae	*Spergula arvensis* L.	AB	Hemicryptophyte	●	●	●
Cleomaceae	*Cleome hirta* (Klotzsch) Oliv.	AB	Therophyte	●	●	○
	Cleome monophyla L.	AB	Therophyte	○	●	●
Commelinaceae	*Commelina benghalensis* L.	AB	Therophyte	●	●	●
Convolvulaceae	*Ipomea plebeia* R. Br. Subsp Africana	AB	Cryptophyte	●	●	●
Cyperaceae	*Fimbristylis exilis* Kunth.	PS	Hemicryptophyte	●	●	●
	Cyperus esculentus L.	PS	Hemicryptophyte	●	●	●
Lamiaceae	*Leucas martinicensis* L.	AB	Therophyte	●	●	●
	Ocimum canum Sims	AB	Therophyte	○	●	○
Malvaceae	*Cochorus tridens* L.	AB	Therophyte	●	●	●
	Hibiscus meeusei Excell.	AB	Phanerophyte	●	●	●
	Sida alba L.	AB	Chamaephyte	●	●	●
Molluginaceae	*Gisekia pharnaceoides* L.	AB	Chamaephyte	●	●	○
Orobanchaceae	*Striga asiatica* (L.) Kuntze	AB	Therophyte	●	●	●
	Alectra vogelii Benth.	AB	Therophyte	○	●	●
Pedaliaceae	*Ceratotheca sesamoides* Endl.	AB	Therophyte	○	●	●
Phyllanthaceae	*Phyllanthus pentandrus* Schumach & Thonn	AB	Therophyte	○	●	●
Poaceae	*Cynodon dactylon* (L.) Pers	PG	Hemicryptophyte	●	●	●
	*Digitaria ternata (*A. Rich) Roem	AG	Therophyte	●	●	●
	Eleusine indica (L.) Gaertn	AG	Therophyte	●	●	●
	Panicum novermnerve Stapf.	AG	Hemicryptophyte	●	●	●
	Setaria pumila (Poir.) Roem. & Schult	AG	Hemicryptophyte	●	●	○
	Melinis repens (Willd) Zizika	AG	Hemicryptophyte	○	●	●
Polygonaceae	*Oxygonum sinuatum* Dammer.	AB	Chamaephyte	●	●	●
Portulacaceae	*Portulaca oleracea* L.	AB	Hemicryptophyte	○	●	○
Rubiaceae	*Richardia scabra* L.	AB	Hemicryptophyte	●	●	●
	Spermacoce senensis (Klotzsch) Hiern	AB	Hemicryptophyte	○	●	●
Zygophyllaceae	*Tribulus terrestris* L.	PB	Therophyte	○	○	●
Total species				24	30	28

Note: ●–weed present, ○–weed absent.

Abbreviations: AB, annual broadleaf; AG, annual grass; ABG, annual broadleaved grass; PB, perennial broadleaf; PG, perennial grass; PS, perennial sedge.

among other weed species. Clustering of the treatments resulted in the formation of two distinct clusters, where sole maize was in its own cluster and the remaining six treatments formed the second cluster. In this second cluster, sole maize with 8 Mg ha^{-1}, maize + cowpea intercropping with four or 8 Mg ha^{-1} mulch recorded the lowest densities.

Weed species were also clustered into two main clusters, with the first cluster made up of the three dominant weeds, and the second cluster was made up of the remaining weed species. However, in the first cluster, *C. dactylon* was further placed in its own distinct cluster because of very high densities observed on red soils on AER 2. Heatmap in Figure 3(b) shows that highest densities of weed species on sandy soils in AER 2 were observed in sole maize without mulch and *C. dactylon* was the most dominant weed, followed by *R. scabra*. In sole maize with 4 Mg ha^{-1}, moderate high density of *R. scabra* was also observed. Treatment clustering resulted in sole maize without maize forming its own cluster and the remaining treatments forming another separate group. From this grouping, it was observed that sole cowpea, maize + cowpea with 4 Mg ha^{-1} and 8 Mg ha^{-1} were most effective in suppressing weeds because of low densities of dominant weeds observed in these treatments.

On red soils in AER 3, sole maize without mulch and sole maize with 4 Mg ha^{-1} were grouped into the same cluster because of high weed densities of *R. scabra*, although sole maize without mulch recorded the highest density (Figure 4(a)). Consequently, *R. scabra* was placed in its own cluster on the dendrogram and the remaining weeds forming another separate cluster. Sole maize with 8 Mg ha^{-1} mulch, sole cowpea and maize + cowpea with 8 Mg ha^{-1} mulch recorded significantly lowest weed densities,

TABLE 3: Relative and total weed density during cropping seasons of 2022–23 and 2023–24 (mean data).

Treatment	Relative weed density %														
	M		MLM		MHM		C		MC		MCLM		MCHM		Overall
Weed species	2022/23	2023/24	2022/23	2023/24	2022/23	2023/24	2022/23	2023/24	2022/23	2023/24	2022/23	2023/24	2022/23	2023/24	2022-24
R. scabra	30.84	31.62	38.86	40.43	30.30	31.32	24.90	15.70	28.76	17.25	26.43	30.62	33.6	34.42	31.30
C. dactylon	22.10	26.46	15.78	13.55	18.88	26.57	27.58	38.92	30.72	57.02	24.16	30.62	18.38	23.36	23.86
F. exilis	9.68	5.44	6.05	4.50	7.25	1.85	10.62	1.35	6.76	1.86	10.04	1.66	9.16	2.36	6.86
B. pilosa	6.53	1.81	7.64	2.15	8.47	1.44	8.58	1.05	6.84	0.69	10.49	2.41	12.14	2.36	5.79
A. hispidum	4.27	1.88	5.53	4.07	6.83	6.39	4.29	2.40	5.72	2.26	7.46	3.02	4.01	4.20	4.44
C. esculentus	3.61	5.26	3.35	3.76	2.89	2.78	2.73	1.65	1.74	0.79	2.04	0.30	4.35	1.84	3.54
D. ternata	3.44	4.17	2.45	2.86	2.32	5.25	0.97	12.72	1.78	3.14	1.14	4.07	0.92	8.92	3.31
L. martinicensis	3.26	2.58	3.63	1.61	7.71	2.57	1.27	2.10	0.81	2.06	2.73	1.51	2.12	1.05	3.06
S. arvensis	2.80	2.67	2.73	12.73	1.94	3.60	3.80	1.95	1.97	0.59	4.32	4.52	3.32	0.52	2.86
S. asiatica	2.65	5.57	2.55	2.66	1.78	4.33	0.00	0.00	0.70	0.10	0.40	1.36	0.17	0.00	2.34
E. indica	1.45	1.56	2.91	1.72	0.46	1.44	1.22	2.69	0.97	1.47	1.69	3.77	3.38	1.31	1.98
C. sesamoides	1.42	3.11	1.08	3.88	0.68	4.02	0.78	2.69	0.89	2.16	1.74	3.32	1.37	7.87	1.72
T. procumbens	1.14	0.88	0.44	0.47	0.57	0.21	1.02	0.45	0.50	0.00	0.45	0.00	0.17	0.26	1.17
C. benghalensis	0.92	1.02	0.93	0.27	2.09	1.96	0.05	1.20	0.70	0.39	0.75	2.87	0.52	1.84	1.17
C. tridens	0.88	0.47	1.60	0.63	1.29	0.41	1.90	0.75	2.01	0.88	1.14	0.30	1.66	1.05	1.09
T. minuta	0.88	1.77	1.13	1.21	0.99	1.44	1.07	0.00	1.39	0.69	0.84	1.36	0.97	1.84	0.95
H. meeusei	0.60	0.57	0.57	0.59	0.72	1.03	0.93	1.95	1.66	0.59	0.30	0.75	0.29	0.52	0.93
C. hirta	0.53	0.50	0.44	1.21	1.86	1.65	0.88	1.80	4.10	1.57	0.99	1.06	1.66	0.26	0.71
T. terrestris	0.53	0.07	0.49	0.00	0.23	0.00	0.05	0.00	0.00	0.00	0.10	0.90	0.00	0.00	0.65
P. novermnerve	0.47	1.75	0.39	0.74	0.34	0.10	0.68	2.69	0.12	3.63	0.75	3.62	0.63	3.41	0.64
P. pentandrus	0.47	0.04	0.18	0.00	0.11	0.00	0.24	0.00	0.04	0.20	0.00	0.00	0.00	0.00	0.21
O. canum	0.33	0.00	0.39	0.00	0.34	0.00	0.29	0.00	0.04	0.00	0.25	0.00	0.40	0.00	0.19
O. sinuatum	0.27	0.02	0.28	0.08	0.23	0.10	0.10	0.60	0.19	0.49	0.00	0.00	0.00	0.26	0.17
S. sinensis	0.23	0.09	0.13	0.16	0.38	0.62	0.44	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.16
G. parviflora	0.13	0.27	0.00	0.16	0.38	0.10	0.10	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.15
I. plebeia	0.12	0.02	0.08	0.12	0.00	0.10	0.00	0.00	0.00	0.20	0.10	0.00	0.00	0.00	0.15
M. repens	0.12	0.04	0.21	0.00	0.11	0.00	0.05	0.00	0.04	0.00	0.05	0.30	0.00	0.26	0.12
Sida alba	0.12	0.04	0.08	0.00	0.04	0.00	0.24	0.30	0.04	0.00	0.00	0.00	0.00	0.00	0.10
C. monophylla	0.08	0.04	0.05	0.12	0.08	0.00	0.05	0.15	0.00	0.00	0.10	0.00	0.06	0.26	0.08
S. pumila	0.08	0.14	0.00	0.00	0.42	0.00	0.05	0.60	0.04	0.88	0.00	0.00	0.00	0.00	0.07
A. hybridus	0.05	0.00	0.00	0.04	0.23	0.31	0.34	0.45	0.00	0.10	0.15	0.60	0.11	0.26	0.06
A. vogelii	0.00	0.00	0.00	0.00	0.00	0.00	4.39	5.54	1.43	0.49	0.99	1.06	0.52	1.05	0.06
G. pharnaceoides	0.00	0.07	0.05	0.16	0.08	0.00	0.39	0.00	0.04	0.10	0.00	0.00	0.00	0.26	0.06
P. oleracea	0.00	0.07	0.00	0.12	0.00	0.41	0.00	0.30	0.00	0.20	0.00	0.00	0.00	0.26	0.05

Note: M—sole maize, no mulch (control), MLM—sole maize + 4 Mg ha^{-1} mulch, MHM—sole maize + 8 Mg ha^{-1} mulch, C—sole cowpea without mulch, MC—maize + cowpea intercrop without mulch, MCLM—maize + cowpea intercrop + 4 Mg ha^{-1} mulch, MCHM—maize + cowpea intercrop + 8 Mg ha^{-1} mulch.

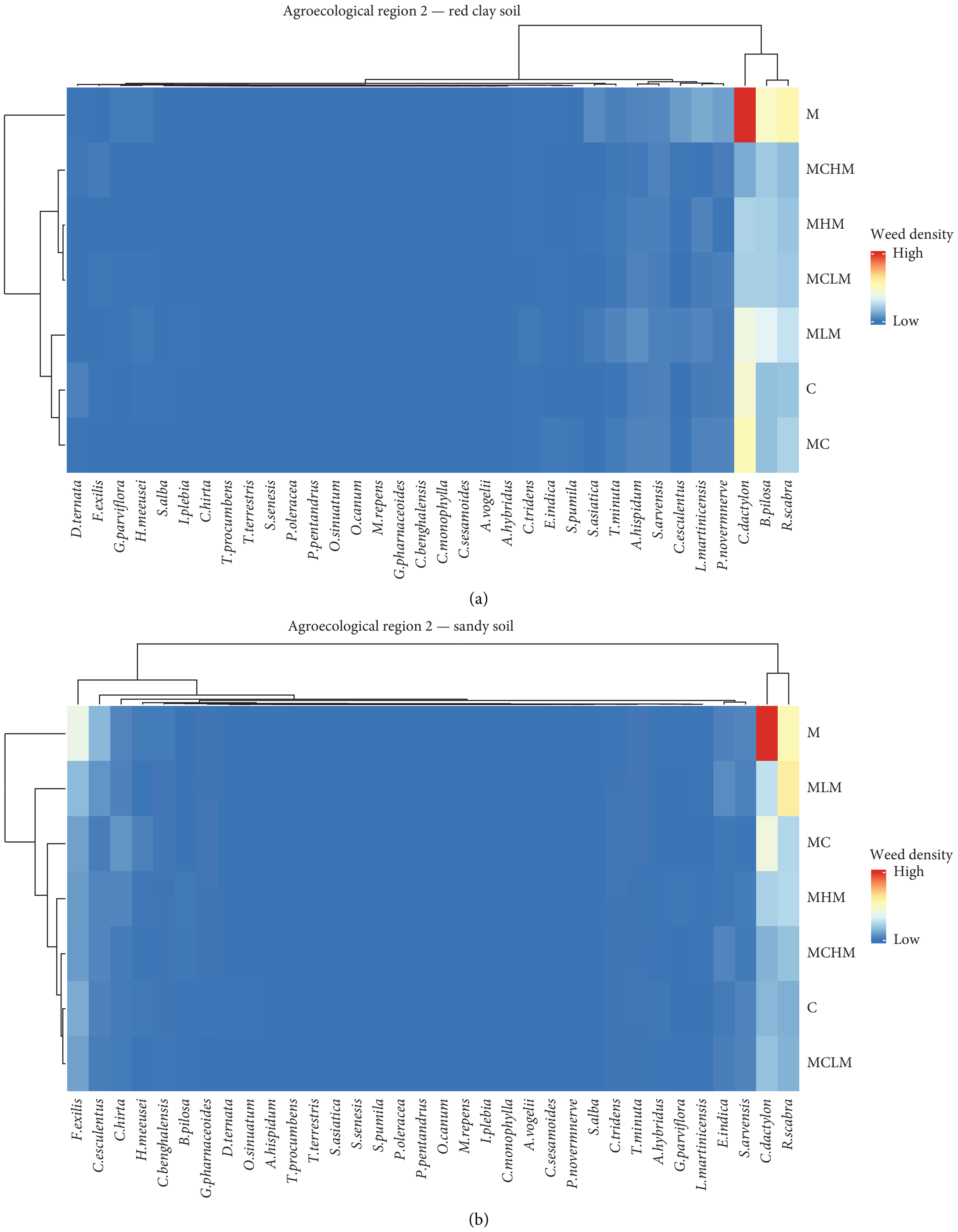
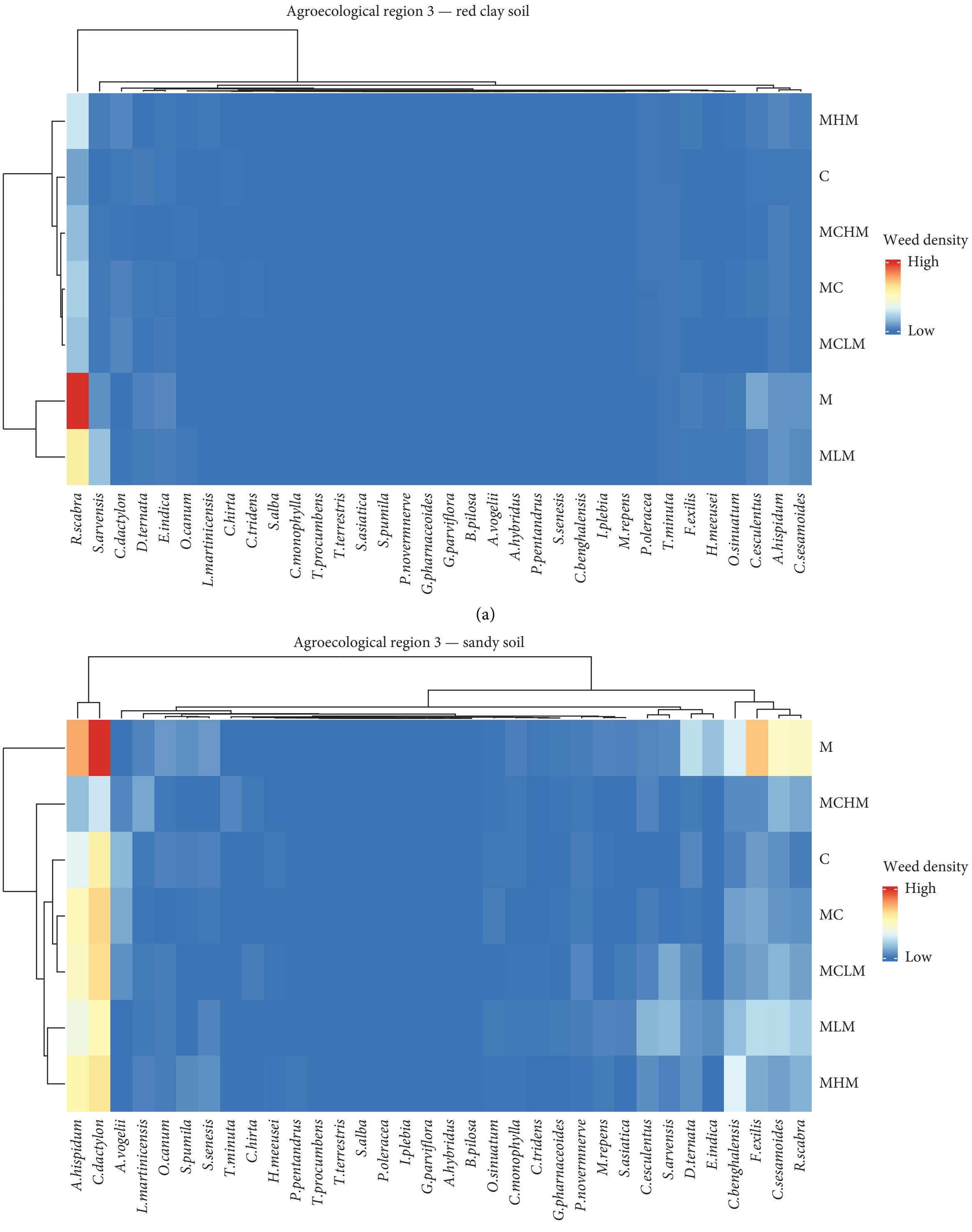


FIGURE 3: Cluster heatmaps of densities of weed species observed in the different treatments on (a) red clay and (b) sandy soils in agroecological region 2. M—sole maize, no mulch (control), MLM—sole maize + 4 Mg ha^{-1} mulch, MHM—sole maize + 8 Mg ha^{-1} mulch, C—sole cowpea without mulch, MC—maize + cowpea intercrop without mulch, MCLM—maize + cowpea intercrop + 4 Mg ha^{-1} mulch, MCHM—maize + cowpea intercrop + 8 Mg ha^{-1} mulch. Data were averaged over two sampling dates during the 2022/23 and 2023/24 seasons at each site in the agroecological region.

specifically sole cowpea which managed to suppress *R. scabra*. On sandy soil in AER 3, it was observed that sole maize without mulch recorded highest number of weed species, namely *A. hispidum, C. dactylon, F. exilis, C. sesamoides* and *R. scabra*, although *C. dactylon* was the most dominant weed (Figure 4(b)). This resulted in sole



(a)

(b)

FIGURE 4: Cluster heatmaps of densities of weed species observed in the different treatments on (a) red clay and (b) sandy soils in agroecological region 3. M—sole maize, no mulch (control), MLM—sole maize + 4 Mg ha^{-1} mulch, MHM—sole maize + 8 Mg ha^{-1} mulch, C—sole cowpea without mulch, MC—maize + cowpea intercrop without mulch, MCLM—maize + cowpea intercrop + 4 Mg ha^{-1} mulch, MCHM—maize + cowpea intercrop + 8 Mg ha^{-1} mulch. Data were averaged over two sampling dates during the 2022/23 and 2023/24 seasons at each site in the agroecological region.

maize without mulch forming its own distinct cluster, while the remaining treatments formed another distinct cluster with moderately higher densities of *A. hispidum and C. dactylon.* Maize + cowpea intercropping with mulch 8 Mg ha^{-1} was found effective in suppressing dominant weed species as compared to other treatments.

In AER 4 and on red clay soils, *R. scabra* was observed to be predominant weed species (Figure 5(a)). The density of this weed was particularly high in sole maize without mulch and moderately high in sole maize with $4\,\mathrm{Mg\,ha^{-1}}$ mulch, which led to the clustering of these two treatments into one cluster. *Striga asiatica* was also observed in sole maize without mulch with a moderate density. The second cluster comprised the remaining five treatments which reduced the densities of the two dominant weed species. Maize + cowpea intercropping with mulching suppressed weeds, with a tendency for better results at the higher mulch rate. In AER4 on sandy soils, *R. scabra* was observed to be the most dominant weed and occupied its own cluster (Figure 5(b)). The remaining weed species were grouped into a second cluster. Weeds such as *D. ternata* and *S. asiatica* in this cluster were associated with sole maize without mulch in moderate densities. Treatment clustering resulted in the formation of two distinct clusters, where the first cluster was made up of sole maize without mulch and sole maize with $4\,\mathrm{Mg\,ha^{-1}}$. In the second cluster, maize + cowpea intercropping with $8\,\mathrm{Mg\,ha^{-1}}$ mulch was most effective in suppressing dominant weeds.

3.4. Effect of Intercropping and Mulching on Weed Species Richness. There were significant ($p < 0.05$) differences among treatments on weed species richness in the different AERs (Figure 6). In AER 2, sole maize without mulch recorded the highest number of individual weed species. However, weed species richness in this treatment was not significantly different from both sole maize with $4\,\mathrm{Mg\,ha^{-1}}$ or $8\,\mathrm{Mg\,ha^{-1}}$ mulch, maize + cowpea without mulch and sole cowpea. The application of mulch in maize + cowpea intercropping either $4\,\mathrm{Mg\,ha^{-1}}$ or $8\,\mathrm{Mg\,ha^{-1}}$ rate resulted in the lowest number of weed species richness. Weed species richness in AER 3 was highest in sole maize without mulch, and the lowest number of species was observed in maize + cowpea with mulch at either $4\,\mathrm{Mg\,ha^{-1}}$ or $8\,\mathrm{Mg\,ha^{-1}}$ and in sole cowpea. In AER 4, sole maize without mulch and sole maize with $4\,\mathrm{Mg\,ha^{-1}}$ recorded the highest number of individual weed species observed as compared to maize + cowpea intercropping with $8\,\mathrm{Mg\,ha^{-1}}$ mulch which recorded lowest weed species richness. Stronger weed species suppression as a result of intercropping coupled with mulching was observed in AER 3 and AER 4 compared with AER 2. However, maize + cowpea intercropping and $8\,\mathrm{Mg\,ha^{-1}}$ mulch were more distinct in AER recording the lowest weed species richness across all the sites.

4. Discussion

This study was conducted to assess the effect of intercropping and mulching on weed flora in three AERs in eastern Zimbabwe. The results of this study suggest that intercropping systems with mulch help to reduce weed infestations and alter the weed community composition.

4.1. Weed Occurrence. Thirty-four weed species belonging to different families and life forms were recorded in this study. Some of the weed species were identified and reported in previous studies conducted in eastern Zimbabwe by Chipomho et al. [22] and Namatsheve et al. [23]. The predominant plant life form in this study was the therophytes followed by hemicryptophytes. Therophytes are plants that are able to rapidly complete their life cycle when conditions are favourable; however, during unfavourable conditions, these plants have developmental plasticity which allows them to produce seed before completing their life cycle and survive as seed [24]. Plants with the hemicryptophyte life form are capable of surviving during unfavourable climatic conditions by protecting buds with withered leaves and the soil [25]. These results agree with the findings of Mncube et al. [26] who also identified therophytes as the dominant life form, followed by hemicryptophytes in maize fields in Eswatini. This can be attributed to crop management practices, such as minimal soil disturbance during hand-hoe weeding, which promotes the spread of annual broadleaved weeds [27]. The differences in the number of weed species observed in the different AERs are mostly dependent on the weed requirements. The combination of moisture and soil temperatures that are variable across the agroclimatic gradient either encourages or prohibits weed occurrence [4].

4.2. Weed Prevalence. *Richardia scabra*, *C. dactylon*, *F. exilis*, *B. pilosa*, *A. hispidum*, *C. esculentus*, *D. ternata* and *L. martinicensis* were the most dominant weed species because of their high relative densities within the diverse weed community. The most dominant weed in this study was *R. scabra*, is highly associated with inherently poor soils and is used as bioindicator of degraded soils [28]. This weed was reported by Chipomho et al. [22] to be an indicator that soil organic carbon stocks are low. Chipomho et al. [13] projected that *R. scabra* was becoming a problematic weed throughout Zimbabwe when it was still ranked as the fourth and sixth most aggressive and difficult to control weed in Mashonaland East, respectively. This is because it can germinate throughout the season and farmers tend to ignore weeding it out towards the end of the growing season. However, this allows the weed to produce a lot of seeds that will be deposited into the soil weed seed bank which acts as a reserve for future weed infestations [1]. The second most dominant weed species was *C. dactylon* which is a perennial grass that is associated with fertile soils and or highly fertilised fields [26]. This result is in support of the findings by Chipomho et al. [13] and Tibugari et al. [29] who reported that *C. dactylon* is now a problematic arable weed in Zimbabwe. Hand-hoe weeding is not effective in controlling this weed because it has rhizomes which go as deep as 0.35 m, at which depth hand weeding is ineffective [3].

4.3. Effect of Intercropping and Mulching on Weed Flora. Experimental results revealed that intercropping and mulching have an influence on the composition and dynamics of weed flora, with weed species response varying depending on the specific treatment. Sole maize without mulch encouraged high weed infestations and predominance of certain weed species. Despite promoting weed proliferation, this system continues to be widely used by

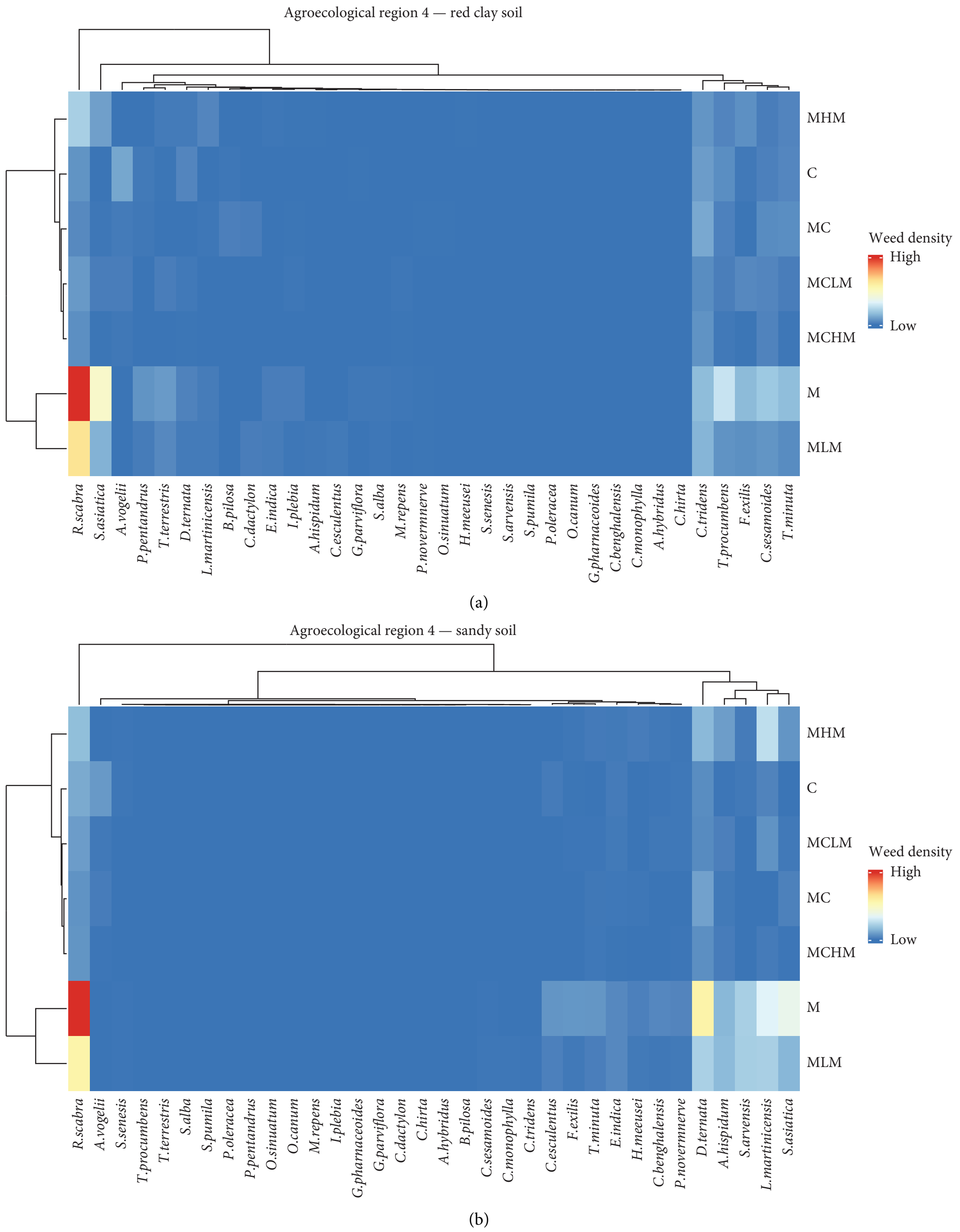


Figure 5: Cluster heatmaps of densities of weed species observed in the different treatments on (a) red clay and (b) sandy soils in agroecological region 4. M—sole maize, no mulch (control), MLM—sole maize + 4 Mg ha^{-1} mulch, MHM—sole maize + 8 Mg ha^{-1} mulch, C—sole cowpea without mulch, MC—maize + cowpea intercrop without mulch, MCLM—maize + cowpea intercrop + 4 Mg ha^{-1} mulch, MCHM—maize + cowpea intercrop + 8 Mg ha^{-1} mulch. Data were averaged over two sampling dates during the 2022/23 and 2023/24 seasons at each site in the agroecological region.

most smallholder farmers in Zimbabwe. Wide row spacing in this system allows for high weed infestations which necessitate frequent weeding. *Cynodon dactylon* and *R. scabra* recorded superiority in this treatment across the agro-climatic gradient, although intercropping and mulching contributed to reducing overall prevalence, except sole

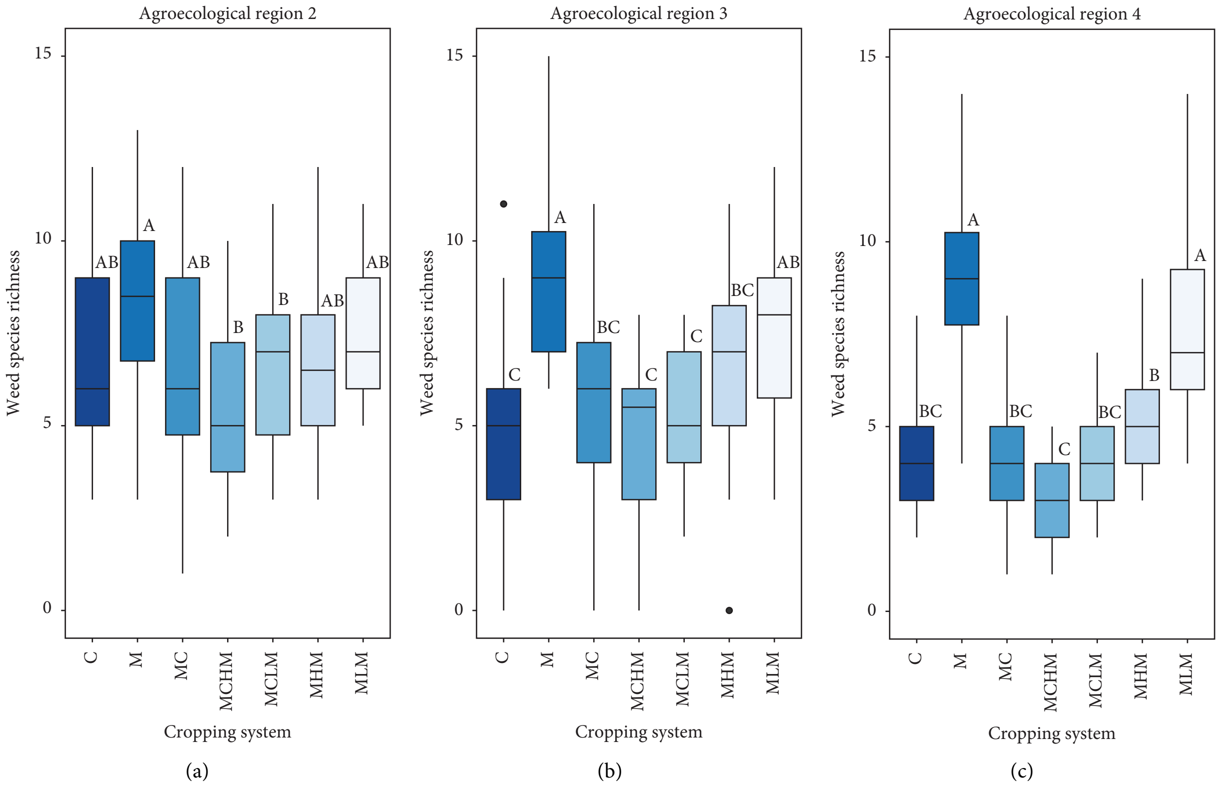


Figure 6: Weed species richness response to different treatments in three agroecological regions. M—sole maize, no mulch (control), MLM—sole maize + 4 Mg ha^{-1} mulch, MHM—sole maize + 8 Mg ha^{-1} mulch, C—sole cowpea without mulch, MC—maize + cowpea intercrop without mulch, MCLM—maize + cowpea intercrop + 4 Mg ha^{-1} mulch, MCHM—maize + cowpea intercrop + 8 Mg ha^{-1} mulch. Data were averaged over two sampling dates and soil types during the 2022/23 and 2023/24 seasons in the agroecological region.

maize with 4 Mg ha^{-1} mulch, intercropping and high rates of mulch were effective in reducing weed predominance. Maize + cowpea intercropping with 4 Mg ha^{-1} mulch was found to be effective in reducing weed dominance in this study. Similar results corroborate with the findings of Bolker et al. [21], who reported that maize + cowpea intercropping reduced the density of *C. benghalensis* which was identified as a major weed in Goromonzi, Zimbabwe. Intercropping and mulching modify the cropping environment that typically promotes weed dominance and makes it less favourable for weeds to thrive [30]. This implies that specific crop management practices can drive weed community characteristics by selecting which weeds survive [10]. These results suggested that intercropping is preferable to continuous cropping; therefore, smallholder farmers can adopt this approach to manage weeds and reduce the prevalence of specific weeds. Intercropping breaks crop–weed interactions that arise because of long-term practice of certain crop management practices. The parasitic weed *S. asiatica* identified as the second dominant weed on sandy soils in AER 4 was effectively suppressed through the intercropping and mulching combination. This suggests that farmers struggling with *S. asiatica* parasitism in maize can benefit from intercropping and mulching. Weed species clustering helped in identifying weed species which thrive in certain cropping systems. This information can help guide the development of customised weed management strategies that target specific weed groups, making farmers to more ably manage weeds. Furthermore, *R. scabra* prevailed on both red clay and sandy soils in all the study sites and this weed is a bioindicator of inherently poor soil. The dominance of this weed on the contrasting soils is a reflection that the soils on smallholder farmers in north-eastern Zimbabwe are depleted of nutrients as a result of continuous cultivation with little nutrient input [31]. Therefore, apart from weed suppression, intercropping with legumes and mulching can improve soil fertility through biological nitrogen fixation and improving soil organic carbon stocks [32, 33].

4.4. Effect of Intercropping and Mulching on Weed Species Richness.

Sole maize without mulch recorded highest number of weed species compared to maize + cowpea intercropping either with 4 Mg ha^{-1} or 8 Mg ha^{-1} mulch, which recorded lowest weed species richness in all the AERs. Intercropping and mulching are crop management practices which have been previously reported to effectively inhibit weed growth. Inter- and intraspecific competition by component crops within an intercropping system helps crops increase crop resource capture, therefore limiting nutrient mining by weeds [34]. This causes a reduction in weed species present as selection favours weed species with better nutrient mining ability. The dense canopy in intercropping also smothers weeds and restricts radiation needed to break the dormancy of photoblastic weed seeds; therefore, weeds with this requirement are suppressed [35]. Mulching forms a physical barrier on the soil surface which hinders weed emergence and consequently weed flora quality and quantity altered [36]. These results concur with the finding of Nwagwu et al. [37] who reported that continuous maize cropping recorded highest weed species richness while intercropping reduced weed species richness. Therefore, intercropping and mulching reduces weed diversity therefore enabling more precise and targeted weed control measures. Stronger impact of intercropping combined with mulching on reducing the number of weeds species present in the weed community under arid conditions in AER 3 and AER 4 than in subhumid conditions in AER 2. In arid environments, intercropping and mulching suppress weed species richness, thereby enabling more targeted and resource-efficient weed management strategies adapted to a simplified weed community structure.

5. Conclusion

Intercropping and mulching reduced weed infestations and dominance of weed species on sandy and red clay soil in AERs. *Richardia scabra* and *Cynodon dactylon* were identified as dominant weed species and were suppressed by maize + cowpea intercropping and mulching. Effective control of parasitic weeds such as *Striga asiatica* in maize was achieved through combined maize + cowpea intercropping and mulching. The observed reduction highlights the potential of these agroecological practices as potential weed management strategies for resource-limited farmers. Weed species richness was reduced by intercropping and mulching. This reduction facilitates targeted weed management interventions by allowing efforts to be concentrated on the remaining problematic species.

Data Availability Statement

Data will be made available upon request.

Disclosure

The contents of this document are the sole responsibility of the authors and can under no circumstances be regarded as reflecting the position of the European Union.

Conflicts of Interest

The authors declare no conflicts of interest.

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