BIODIVERSITAS
Volume 24, Number 1, January 2023
Pages: 399-414

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d240147

Composition and diversity patterns of weeds in herbicide tolerant maize fields and margins in the Eastern Cape, South Africa

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Manuscript received: 31 October 2022. Revision accepted: 15 January 2023.

Abstract. *Kwinda M, Siebert SJ, Van Coller H, Masehela TS. 2023. Composition and diversity patterns of weeds in herbicide tolerant maize fields and margins in the Eastern Cape, South Africa. Biodiversitas 24: 399-414.* Weeds are considered undesirable plants that grow where they are not wanted, as they often outcompete crops and other beneficial plant species. This study aimed to compare species composition and diversity of weedy plant communities in fields planted with herbicide tolerant maize and associated field margins in the Eastern Cape Province, South Africa. A total of 88 weed species, representing 31 families were recorded from 244 plots for maize fields and field margins combined. The maize fields and margins across the four sites shared 53% of the species. Non-metric Multidimensional Scaling grouped maize fields and field margins separately based on weed species composition. Moreover, maize fields and margins differed significantly in terms of Simpson (p=0.044) and Shannon indices (p=0.003), with diversity being higher in the fields. This study confirms that maize fields have a dissimilar composition of weedy species and dissimilar diversity to that of field margins. This result enables farmers to know whether current herbicide use is sufficient for targeted weed control in fields and margins. The findings and knowledge will benefit maize farmers and future researchers working on weeds in Sub-Saharan Africa when it comes to the development, implementation, and prioritization of various herbicide-based weed management protocols to ensure maximum crop productivity.

Keywords: Composition, diversity, herbicide tolerant, maize, weeds

INTRODUCTION

Weed invasions within landscapes have received considerable attention globally and brought about different views on their potential impacts on various productive systems (Hadi et al. 2014). Weeds are considered undesirable plant species that grow in areas where they are not wanted, such as crop fields and roadsides. However, not all weeds are detrimental to the environment where they occur (Ramesh et al. 2017). Some weeds can be important for various ecosystem services in agricultural lands, such as providing habitat and supporting prey species for higher trophic levels (Ramesh et al. 2017). However, in agricultural systems, weeds have been shown to compete with most crops for resources, causing reductions in harvest yields (Madden et al. 2021). Weeds compete for water, sunlight, and nutrients that are essential for crop growth and productivity. Consequently, weed control and eradication remain necessary within agricultural systems to ensure optimum crop yield (Madden et al. 2021).

It is well known that different crop fields vary in weed species composition, diversity, and abundance (Travlos et al. 2018). These differences are dependent on local historical agronomic practices, such as soil tillage, agrochemical use, habitat fragmentation, prevailing climate, soil type, and topography (Sims et al. 2018). In some instances, persistent seedbanks also facilitate weed diversity and reflect historical management practices of a particular field (Hadi et al. 2014). Hadi et al. (2014) and Khan et al. (2017) reported that weed species commonly found inside maize crop fields, in general, belong to plant families, such as Apiaceae, Asteraceae, Brassicaceae, Caryophyllaceae, Chenopodiaceae, Convolvulaceae, Cyperaceae, Euphorbiaceae, Fabaceae, Lamiaceae, Malvaceae, Oxalidaceae, Plantaginaceae, Poaceae, Polygonaceae, and Solanaceae. In addition, field margins are also likely to be dominated by alien species due to prevailing disturbances, such as grazing, with animals able to transfer seeds from one area to colonize another area (Khan et al. 2017). Subsequently, maize field margins are considered more diverse in weed species than maize fields (Botha et al. 2017).

Herbicide tolerant (HT) maize incorporates genes that tolerate specific broad-spectrum herbicides which kill the surrounding weeds, but leave the cultivated crop unharmed. Excessive use of herbicides often contaminates surrounding areas, resulting in environmental concerns. Also, there are many problems associated with weeds developing resistance if herbicide mixes are not applied correctly. These problems can only be overcome if farmers have good knowledge and training opportunities and are able to make use of the correct chemical methods to control and eradicate weeds and apply the tested protocols to overcome herbicide resistance in weeds (Schütte et al. 2017). The assessment and profiling of weeds have always been an important tasks to guide the management of agricultural activities to protect crop productivity and prevent invasion of the surrounding environment (MacLaren et al. 2020). Weed persistence under current weed control measures in herbicide tolerant maize will inform as to whether current herbicide use is sufficient to ensure sustainable maize production or not.

Tokarska-Guzik et al. (2014) indicated that weed assemblages in maize fields are dominated by species pre-adapted to tolerate field-specific herbicide use, which could result in similar weed species composition on different fields. Differences between maize fields and margins may be ascribed to differences in management practices, as the field margins are less disturbed compared to fields that experience exogenous disturbance, such as soil tillage (Tokarska-Guzik et al. 2014). This study aimed to compare the species composition and diversity of weedy plant communities in fields planted with herbicide tolerant maize and associated field margins in the Eastern Cape Province, South Africa. In this paper, maize fields refer to genetically modified HT maize. It is hypothesized that maize systems would have similar weed composition and diversity across fields but will differ between maize fields and field margins.

MATERIALS AND METHODS

Study area

The study was conducted in Baziya and Tsolo areas that fall under the Oliver Tambo District Municipality in the Eastern Cape (EC) Province of South Africa. Baziya is part of the King Sabata Dalindyebo Local Municipality, whereas Tsolo falls under the Mhlontlo Local Municipality. Tsolo can be described as a small town about 41 km north-west of Mthatha (capital of the former Transkei region), and Baziya is a village situated approximately 40 km southeast of Mthatha. The district is mainly rural; hence smallholder croppings, such as wheat, maize, sorghum, and vegetables and livestock raising, are the primary economic activities in the area (Kibirige et al. 2019).

The climate in the region is mild, generally warm and temperate (Mahlalela et al. 2020). The province receives progressively more precipitation from west to east, with Mthatha (744 mm) and Tsolo (801 mm) receiving a substantial amount of rainfall during the year, even in the driest months. The average annual temperature in Mthatha is 17ºC and 16.2ºC in Tsolo (Table 1). Winter frost is more common for Tsolo, receiving approximately 11 days per annum, compared to Mthatha, which receives four days per annum.

Baziya and Tsolo regions have fertile soil with a clay fraction of organic matter and minerals. This resembles a more tropical and subtropical soil type (Mahlalela et al. 2020). In terms of vegetation (Table 1), the Baziya and Tsolo regions are largely thornveld, subtropical evergreen forests and grassland (Mahlalela et al. 2020). The grasslands and savannas are dominated by a large variety of grasses and forbs, with few shrubs and trees (Muller et al. 2021).

Procedures

Site selection

Study sites were selected with the assistance of GrainSA's Mthatha office. Areas with little to no data or knowledge of weed species records for HT maize fields in the region were prioritized. Smallholder farmers chosen for the study fell within the GrainSA development program, whereby they receive various levels of training, resources, and mentorship for maize farming. In addition, GrainSA is responsible and facilitates the spraying protocols (for different herbicides) used by farmers in the region to manage/control weeds in HT maize fields.

In Baziya, three sites were selected for sampling, which included Makaula, Jojweni and Mission (Figure 1). Sampling sites in Tsolo are presented in Figure 2. Ten maize fields were selected for sampling in Makaula, five in Jojweni, and six in Mission. A total of 21 maize fields were selected for sampling in Baziya, which constituted 28 ha. In Tsolo, seven maize fields were selected for surveys making up a total area of 7 ha. Maize field size, in hectares, was measured using a Global Positioning System by walking the perimeter of a field.

Sampling design

A typical HT maize agroecosystem comprises two main areas, namely the maize field and the maize field margin. The zone inside the maize fields bordering the field margin, is called the field edge. The zone of the field margin bordering the maize field is called the field boundary (Figure 3).

Table 1. Climate details for the biomes, vegetation units and the regions of Mthatha, Tsolo and Baziya, South Africa (Mahlalela et al. 2020)

Biome	Vegetation unit	Bioregion	Subregion	MAP	MAT	MFD
Grassland	Dry Coast Hinterland Grassland	Sub-Escarpment Grassland Bioregion	Tsolo	887	14.6	26
Grassland	Mthatha Moist Grassland	Lowveld Bioregion	Tsolo, Baziya, Mthatha	743	16.2	5
Grassland	Eastern Valley Bushveld	Lowveld Bioregion	Tsolo, Baziya, Mthatha	773	17.8	3
Savanna	Zululand Lowveld	Lowveld Bioregion	Mthatha, Baziya	717	17.0	3

Note: MAP: Mean annual precipitation (mm); MAT: Mean annual temperature (ºC); MFD: Mean frost days per annum

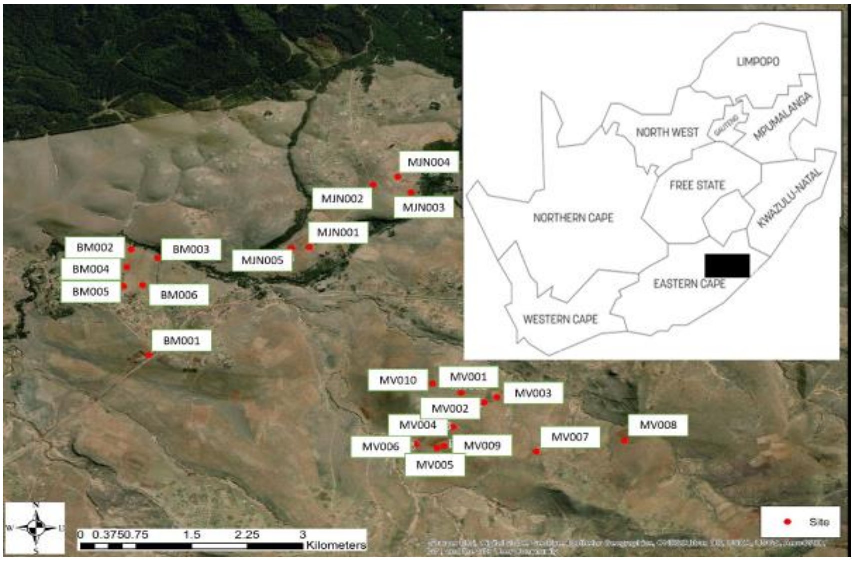

Figure 1. The locality of Baziya study sites (red dots) in the Oliver Tambo District of the Eastern Cape, South Africa (indicated by a black rectangle on the insert map of South Africa). Maize fields of different sites are: MJN: Baziya Jojweni; MV: Baziya Makaula; and BM: Baziya Mission (Fhatani 2019)

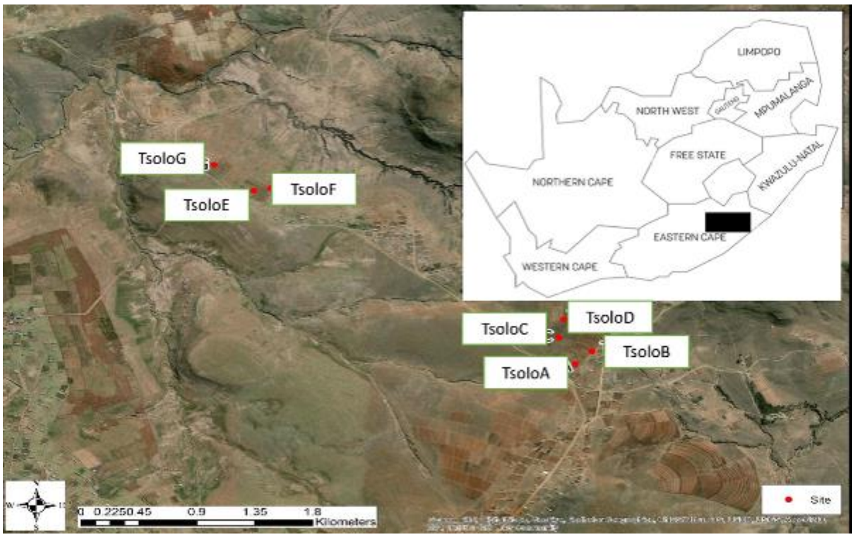

Figure 2. The locality of Tsolo study sites (red dots) in the Oliver Tambo District of the Eastern Cape, South Africa (indicated by a black rectangle on the insert map of South Africa). Maize fields of different sites are presented (Fhatani 2019)

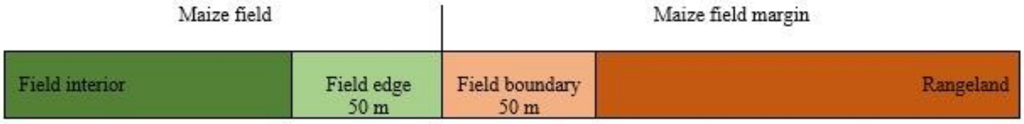

Figure 3. Structural definition of field edge (50 m) and boundary (50 m) in a maize agroecosystem

The criteria to sample the defined agroecosystem (Figure 3) was adopted from a protocol established during a 2017/18 pilot study (hereafter referred to as season one). The sampling design followed a similar approach to that of Botha et al. (2015), with some modifications. The lack of uniformity in EC maize fields (i.e., smaller size, length, and width) informed modifications, leading to three transects being sampled (Reference Transect=RT, Edge Transect=ET, and Centre Transect=CT). Three sampling criteria were developed to determine the placement of the different transects (Figures 4, 5, and 6). In the sampling criteria, a control transect to sample conventional or non-HT maize was not accounted for since no comparable sites with non-HT maize or of similar field sizes were present in the surrounding area. Although it would have been an option to have a control in a different region within the same province, this was not considered as the geology, soil, and microclimate in the respective regions were likely to be highly variable and affect weed species composition.

The number of times (repeats) that each maize field could be surveyed was dependent on each participating farmer's preference in terms of farming inputs (dependent on economic circumstances) for possible ploughing/ planting and environmental factors. In addition, the farmer's willingness to be guided/mentored on what time is best for the ploughing and herbicide application timeframes and protocols also determined the number of repetitions. October to November was targeted for pre-ploughing surveys (Table 2).

After ploughing, a pre-emergence herbicide was sprayed between three and seven days after planting, followed by post-emergence spraying five to six weeks after germination of the maize crop. Post-ploughing and seed-sowing surveys were conducted on or before the period of post-emergence herbicide application (5^{th}-6^{th} week) in late January to early February, depending on when the planting season had started (Table 2).

Placement of transects

Transects were established per field according to three criteria: (i) field length and width, (ii) field margin vegetation to accommodate RTs, and (iii) space to construct three transects where possible. Compass direction did not dictate the placement of transects, as field length was the most important to consider. Transect placement occurred as follows: up to three transects (one CT and two ETs) were placed inside the field parallel to one another and along the longer side of the field. These transects captured weed diversity subjected to agricultural disturbance, such as ploughing and herbicide applications. The reason for establishing three transects was to capture sufficient variability in plant species composition. Quadrats were sampled every 10 m along the transect lines. ETs could not be placed in all fields if the 50 m spacing could not be adhered to.

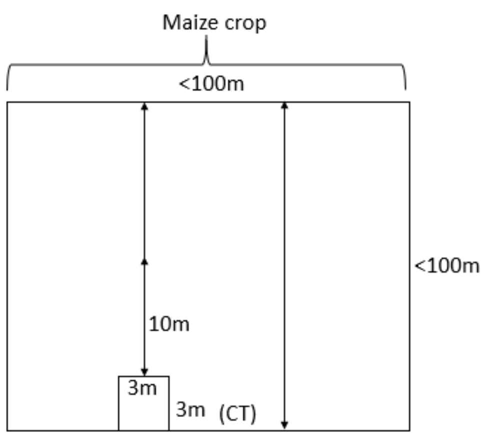

Figure 4. Criterion 1 for weed sampling. When both sides (length and width) of a maize field were less than 100 m in length, then only a center transect could be sampled in the field interior. Edge and reference transects were absent. At 10 m intervals, 3x3 m quadrats/plots were sampled

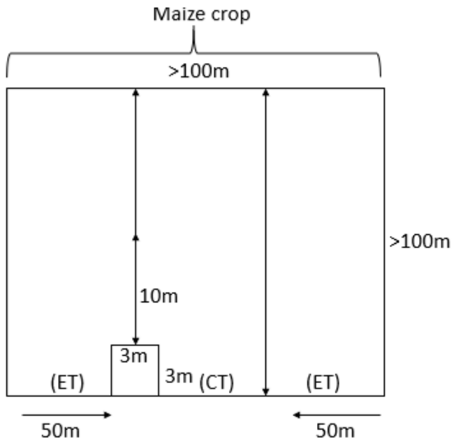

Figure 5. Criterion 2 for weed sampling. When at least one side (length and width) of a maize field was greater than 100 m, then a central transect in the field interior and two edge transects in the field edge were sampled. Reference transects were absent. At 10 m intervals, 3x3 m plots were sampled

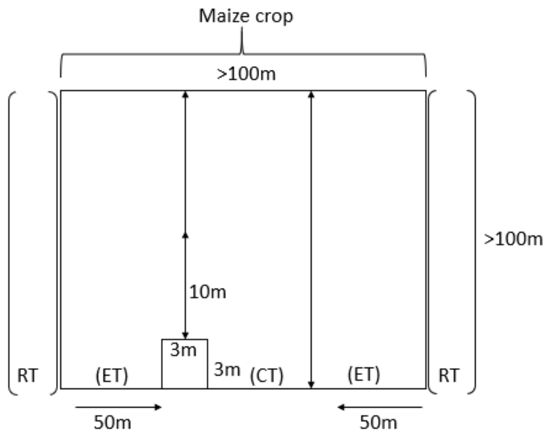

Figure 6. Criterion 3 for weed sampling. When at least one side (length and width) of a maize field was greater than 100 m, and a field margin was present, then a center transect in the field interior, two edge transects in the field edge and two reference transects in the field boundary were sampled. At 10 m intervals, 3x3 m plots were sampled

Table 2. Explanation of what pre-ploughing and post-ploughing and seed-sowing surveys entail

Survey type	Pre-ploughing	Post-ploughing and seed-sowing
Ploughing	No	Yes
Planting	No	Yes
Pre-emergence herbicide	No	Yes
Seedling emergence	No	Yes
Post-emergence herbicide	No	Yes

Sampling of transects

Only maize fields planted with HT maize were sampled. The maize cultivar used in season one was different from that of seasons two and three. Season one (2017/18) used NK603XMON810 maize, whereas seasons two and three (2018/19 and 2019/20) used MON89034. The change in maize cultivars had no effect on this study because both cultivars (NK603XMON810 and MON89034) confer insect resistance and herbicide tolerance traits. This was important as it allowed the study to still focus on the main objectives regarding herbicide effects on weeds in HT maize fields.

In each field, every 3x3 m^2 was measured out with a measuring tape, and the four corners were marked with metal droppers (1.5 m in height). The weed species and the total number of individuals were recorded per quadrat using a pre-designed data sheet. Weed species were identified up to species level (Fish et al. 2015) and unidentified taxa were collected, pressed, and identified by Compton Herbarium, Kirstenbosch Research Centre or the AP Goossens Herbarium, North-West University. Full details and sampling frequencies of all sites in Baziya and Tsolo are given in Table 3.

Data analysis

Rarefaction curves were drawn in PRIMER 6 to assess sampling effort across sites and treatments and considered total species richness (Sobs), Chao's estimator based on the number of rare species (Chao1), Chao's estimator using presence-absence data (Chao2) and a Bootstrap estimator based on the proportion of quadrats containing each species.

Weed species composition

To determine the compositional similarity of weed species between sites of HT maize fields and field margins, non-metric multidimensional scaling (NMDS) analysis was applied in PRIMER 6 (Bliss et al. 2017). This analysis was performed using Bray-Curtis similarity and square root transformation to balance the contribution of highly abundant and rare species (Kent 2012). Stress values of Bray-Curtis similarity distance measures can be interpreted as follows: i) <0.05 gives an excellent representation with no misinterpretation; ii) <0.1 corresponds to a good ordination; iii) <0.2 gives a potentially good and useful two-dimensional picture; iv) >0.3 can be considered poor and difficult to interpret (Bliss et al. 2017).

PERMANOVA (permutations = 999; type III sums of squares) was selected in PRIMER 6 to test for significant differences in weed species composition between the two surveys (pre-ploughing versus post-ploughing and seed-sowing) and between sites (MV, MJN, BM, and T) over three seasons (Hunter 2017). PERMANOVA does not require specific assumptions for normality (Linstädter et al. 2016). To distinguish between significant different treatments, a pairwise comparison of PERMANOVA analysis was performed.

To determine which weed species were responsible for the changes in composition and to calculate the contribution of each species' percentage to the similarity between sites, a Similarity Percentage Analysis (SIMPER) was carried out in PRIMER 6 (Hunter 2017). The same data matrix used for NMDS was used for SIMPER to determine the species percentage contribution.

Quantifying weed species diversity

The data set containing abundance of weeds with corresponding HT maize fields was used to calculate diversity indices per site over three seasons in PRIMER 6 (Table 4). To provide a full overview of weed species richness and diversity patterns, these matrices were used in combination as they display different aspects of diversity.

RESULTS AND DISCUSSION

Rarefaction and richness estimates for maize fields and margins

Sampling-based rarefaction curve estimates of maize fields and field margins indicated sufficient sampling effort for maize fields and insufficient sampling for field margins (Figures 7A and 7A). Less sufficient sampling for field margins occurred (36 versus 208 quadrats in maize fields), because some fields were fenced and in close proximity to one another, making the sampling of margins difficult.

Plant species of maize fields and field margins

A total of 74 weed species were recorded within the 208 sampled maize field quadrats (Table 5). Richness estimators suggested richness in the community to be 80 for all four estimators (Sobs, Chao1, Chao2, and Bootstrap) (Figure 7A). However, in the 36 sampled quadrats for field margins, 61 weed species were recorded (Table 6) and the richness estimator suggested the richness in the community to be 60+ and increasing for the three estimators (Sobs, Chao1, and Bootstrap), except for Chao2 which was 80+ (Figure 7B).

Plant species of maize fields and field margins

A greater number of forb species than grass species were recorded in the agroecosystem, with a higher number of indigenous species (55%) compared to invasive species (45%) (Table 5). Dominant families in both maize fields and field margins were Poaceae (30), followed by Asteraceae (28), Fabaceae (14), and Cyperaceae (9).

Maize fields had a higher number of total weed and alien species compared to field margins. However, these results need to be considered with caution, as field margins were under-sampled. Twenty-five plant families were recorded in both the maize fields and field margins (Table 6). A Venn diagram indicated that maize fields comprised 31% unique species compared to field margins which revealed 16% unique species. The shared species between maize fields and field margins were 53% (Figure 8). A total of 39 alien species were recorded in maize fields, whilst 35 of the recorded species were indigenous (Table 6).

Table 3. Details of the sampling frequencies across sampling sites for three seasons

Site name	Maize field name	Total number of transects	Complete data for season one (2017/18)	Pre-ploughing survey	Post-ploughing and seed-sowing survey	Complete data for season two (2018/19)	Pre-ploughing survey	Post-ploughing and seed-sowing survey	Complete data for season three (2019/20)	Pre-ploughing survey	Post-ploughing and seed-sowing survey	Reference transects
Baziya Makaula	MV001	3	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes
	MV002	3	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	MV003	3	Yes	Yes	Yes	No	Yes	No	No	No	No	Yes
	MV004	1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	MV005	3	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes
	MV006	1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
	MV007	3	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes
	MV008	3	Yes	Yes	Yes	No	Yes	No	No	No	No	Yes
	MV009	3	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	MV010	3	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Baziya Mission	BM001	3	No	Yes	No	No	No	No	No	No	No	No
	BM002	3	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes
	BM003	3	Yes	Yes	Yes	No	Yes	No	No	No	No	Yes
	BM004	3	Yes	Yes	Yes	No	No	No	No	No	No	Yes
	BM005	3	Yes	Yes	Yes	No	No	No	No	No	No	Yes
	BM006	3	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Baziya Jojweni	MJN001	1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
	MJN002	3	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes
	MJN003	1	No	Yes	No	No	No	Yes	Yes	Yes	Yes	No
	MJN004	1	No	Yes	No	No	No	Yes	Yes	Yes	Yes	No
	MJN005	1	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No
Tsolo	TA	1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
	TB	1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
	TC	1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
	TD	1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	TE	1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
	TF	1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	TG	1	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: Yes: represent that sampling was conducted for that season; No: represent the opposite; Pre: represents pre-ploughing survey and Post: represents post-ploughing and seed-sowing survey

Weed species responsible for community dissimilarities

Species responsible for differences between communities were considered those that made a percentage contribution of more than 5% to the dissimilarity between treatments. Only 11 weed species contributed >5% to the dissimilarity. High abundances of *Cynodon dactylon*, *Richardia brasiliensis*, and *Sonchus nanus* were recorded in the margins and contributed the most to the dissimilarity between maize fields and field margins (Table 7a). Weed species with high mean abundance in the maize fields compared across sites were *Cotula carinatum*, *Cynodon dactylon*, and *Helichrysum griseolanatum* in the MV site (Table 7b-d), *Amaranthus viridis*, *Cyperus* sp. and *Cynodon dactylon* in the BM site (Table 7b, e, f), *Cyperus* sp. for MJN (Table 7c, e, g) and *Helichrysum asperum* for T (Table 7d, f, g). Weed species with high mean abundance in margins compared across sites were *Arctotheca calendula*, *Helichrysum griseolanatum*, and *Cynodon dactylon* in MJN (Table 7h, k, l), *Cynodon dactylon* and *Sonchus nanus* in BM (Table 7h-j), *Richardia brasiliensis* for MV (Table 7i, k, m) and *Richardia brasiliensis* and *Sonchus nanus* for T (Table 7j, l, m). *Cynodon dactylon* was the only species found across all sites as part of the weed species that contributed more than 5% of the average dissimilarity across the fields.

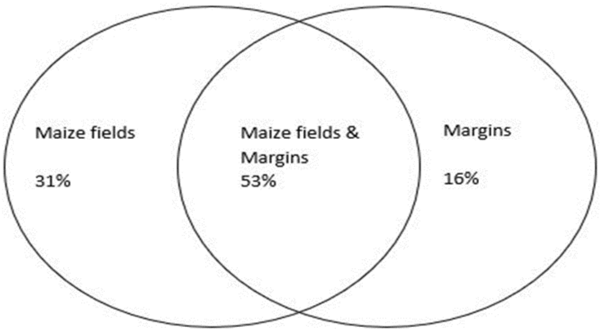

Figure 8. Venn diagram indicating the percentage of unique and shared species between the maize fields and field margins

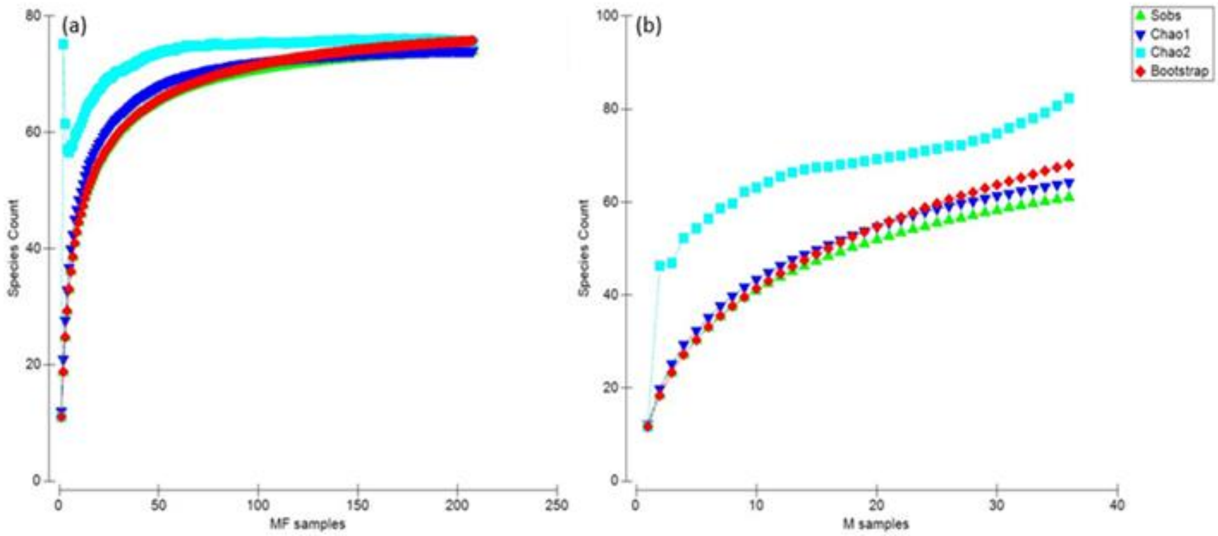

Figure 7. Sample-based rarefaction curves for: (A) maize fields surveys and (B) margins, with species richness estimates based on all weed species discovered (Sobs), Chao's estimator based on the number of rare species (Chao1), Chao's estimator using just presence-absence data (chao2) and a Bootstrap estimator based on the proportion of transects containing each species

Table 4. Equations used to calculate indices of weed species diversity

Indices	Equation	Description	Reference
Species richness (S)	NA	Number of species per field.	Morris et al. (2014)
Abundance (N)	NA	The number of individuals per species per field.	Morris et al. (2014)
Margalef's species richness (d)	$(d) = \frac{(S-1)}{\ln N}$	S is the number of species and N is the number of individuals in the sample.	Margalef (1958)
Simpson's diversity index (Ď)	$(\check{D}) = \frac{\Sigma ni(ni-1)}{N(N-1)} - 1$	N is the total number of individuals for the species, ni is the number of individuals for the i'th species.	Simpson (1949)
Shannon-Wiener diversity index (H')	$(H') = -\Sigma pi.\ln pi$	pi is the relative abundance of the i'th species.	Shannon (1948)
Pielou's evenness index (J')	$(J') = H'/H'max = \frac{H'}{\ln S}$	H' is the Shannon-Wiener diversity index. S is the species richness.	Pielou (1975)

Table 5. List of species recorded for maize fields and margins in Baziya and Tsolo, South Africa

Family	Scientific name	Common name	Growth form	Indigenous/ alien	Maize fields (MF)	Field margins (M)	Both (MF & M)
Amaranthaceae	*Amaranthus viridis* L.	Spiny pigweed	Forb	Alien	Present	Present	Present
Apiaceae	*Daucus carota* L.	Wild carrot	Forb	Alien	Present	Present	Present
Asparagaceae	*Asparagus* sp.	Asparagus	Forb	Indigenous	Absent	Present	Absent
Asteraceae	*Arctotheca calendula* K. Lewin	Capeweed	Forb	Indigenous	Present	Present	Present
Asteraceae	*Berkheya onopordifolia* (DC.) Burtt Davy	Purple berkheya	Forb	Indigenous	Present	Absent	Absent
Asteraceae	*Bidens bipinnata* L.	Spanish needles	Forb	Alien	Present	Present	Present
Asteraceae	*Bidens pilosa* L.	Jersey cudweed	Forb	Alien	Present	Present	Present
Asteraceae	*Cirsium vulgare* (Savi) Ten.	Spear thistle	Forb	Alien	Present	Absent	Absent
Asteraceae	*Erigeron bonariensis* L.	Argentine fleabane	Forb	Alien	Present	Present	Present
Asteraceae	*Cotula heterocarpa* DC.	Water buttons	Forb	Indigenous	Present	Present	Present
Asteraceae	*Galinsoga parviflora* Cav.	Galant soldier	Forb	Alien	Present	Absent	Absent
Asteraceae	*Helichrysum asperum* (Thunb.) Hilliard & B.L.Burtt	Hairy everlasting	Forb	Indigenous	Present	Present	Present
Asteraceae	*Helichrysum griseolanatum* Hilliard	Fluffy white	Forb	Indigenous	Present	Present	Present
Asteraceae	*Oncosiphon pilulifer* (L.f.) Källersjö	Pineapple weed	Forb	Indigenous	Present	Absent	Absent
Asteraceae	*Pseudognaphalium luteoalbum* (L.) Hilliard & B.L.Burtt	Jersey cudweed	Forb	Indigenous	Present	Present	Present
Asteraceae	*Sonchus asper* (L.) Hill	Prickly sow-thistle	Forb	Alien	Present	Present	Present
Asteraceae	*Sonchus nanus* Sond. ex Harv.	Sowthistle	Forb	Alien	Present	Present	Present
Asteraceae	*Tagetes minuta* L.	Khaki weed	Forb	Alien	Present	Present	Present
Asteraceae	*Xanthium spinosum* L.	Spiny cocklebur	Forb	Alien	Present	Present	Present
Brassicaceae	*Rorippa nudiuscula* (E.Mey. ex Sond.) Thell.	Yellowcresses	Forb	Alien	Present	Present	Present
Campanulaceae	*Lobelia erinus* L.	Garden lobelia	Forb	Indigenous	Present	Present	Present
Campanulaceae	*Wahlenbergia stellarioides* Cham.	Tufted bluebell	Forb	Indigenous	Present	Present	Present
Amaranthaceae	*Dysphania carinata* (R.Br.) Mosyakin & Clemants	Keeled goosefoot	Forb	Alien	Present	Present	Present
Cleomaceae	*Cleome monophylla* L.	Rocky mountain beeplant	Forb	Indigenous	Present	Absent	Absent
Commelinaceae	*Commelina benghalensis* L.	Benghal dayflower	Forb	Alien	Present	Present	Present
Convolvulaceae	*Ipomoea purpurea* (L.) Roth	Common morning glory	Forb	Alien	Present	Present	Present
Convolvulaceae	*Ipomoea* sp.	Bindweed	Forb	Alien	Present	Absent	Absent
Cucurbitaceae	*Cucumis myriocarpus* Naudin	Gooseberry cucumber	Forb	Indigenous	Present	Present	Present
Cunoniaceae	*Callicoma serratifolia* Andrews	Black wattle	Forb	Alien	Present	Present	Present
Cyperaceae	*Bulbostylis humilis* (Kunth) C.B.Clarke	Bushy heads grass	Sedge	Indigenous	Present	Absent	Absent
Cyperaceae	*Cyperus congestus* Vahl	Nut grass	Sedge	Indigenous	Present	Absent	Absent
Cyperaceae	*Cyperus esculentus* L.	Tigernut	Sedge	Indigenous	Present	Absent	Absent
Cyperaceae	*Cyperus* sp.	Sedges	Sedge	Indigenous	Present	Present	Present
Euphorbiaceae	*Euphorbia prostrata* Aiton	Green creeping spurge	Forb	Alien	Present	Present	Present
Euphorbiaceae	*Ricinus communis* L.	Castor bean	Forb	Alien	Present	Absent	Absent
Fabaceae	*Alysicarpus rugosus* (Willd.) DC.	Red moneywort	Forb	Indigenous	Present	Present	Present
Fabaceae	*Chamaecrista biensis* (Steyaert) Lock	Locust weed	Forb	Indigenous	Present	Present	Present
Fabaceae	*Indigofera spicata* Forssk.	True indigo	Forb	Indigenous	Present	Absent	Absent
Fabaceae	*Lespedeza pilosa* (Thunb.) Siebold & Zucc.	Carlifonia bush clover	Forb	Alien	Present	Absent	Absent
Fabaceae	*Medicago polymorpha* L.	California burclover	Forb	Indigenous	Present	Present	Present
Fabaceae	*Tephrosia capensis* (Jacq.) Pers.	Tephrosia fern	Forb	Alien	Present	Present	Present
Fabaceae	*Trifolium repens* L.	White clover	Forb	Alien	Present	Present	Present
Fabaceae	*Zornia capensis* Pers.	Caterpillar bean	Forb	Indigenous	Present	Present	Present

Gisekiaceae	*Gisekia pharnaceoides* L.	Sand herbage	Forb	Alien	Present	Present	Present
Hypoxidaceae	*Hypoxis villosa* L.f.	Golden winter star	Forb	Indigenous	Present	Present	Present
Iridaceae	*Aristea abyssinica* Pax	Blue-eyed grass	Forb	Indigenous	Present	Absent	Absent
Malvaceae	*Hibiscus nigricaulis* Baker f.	Wild stockrose	Forb	Indigenous	Present	Absent	Absent
Malvaceae	*Hibiscus trionum* L.	Flower-of-an-hour	Forb	Indigenous	Present	Present	Present
Onagraceae	*Oenothera parodiana* Munz	Evening primrose	Forb	Alien	Present	Present	Present
Papaveraceae	*Argemone mexicana* L.	Mexican prinkly poppy	Forb	Alien	Present	Absent	Absent
Papaveraceae	*Papaver aculeatum* Thunb.	Orange poppy	Forb	Indigenous	Present	Absent	Absent
Scrophulariaceae	*Diclis reptans* Benth.	Toadflax	Forb	Indigenous	Present	Present	Present
Plantaginaceae	*Plantago virginica* L.	Dwarf plantain	Forb	Alien	Present	Present	Present
Poaceae	*Andropogon eucomus* Nees	Snowflake grass	Grass	Indigenous	Absent	Present	Absent
Poaceae	*Arundinella furva* Chase	Tambuki grass	Grass	Indigenous	Absent	Present	Absent
Poaceae	*Urochloa deflexa* (Schumach.) H. Scholz	Congo signal grass	Grass	Indigenous	Absent	Present	Absent
Poaceae	*Moorochloa eruciformis* (Sm.) Veldkamp	Velvet bushwillow	Grass	Indigenous	Absent	Present	Absent
Poaceae	*Bromus diandrus* Roth	Great brome	Grass	Alien	Present	Absent	Absent
Poaceae	*Cynodon dactylon* (L.) Pers.	Couch grass	Grass	Alien	Present	Present	Present
Poaceae	*Digitaria argyrograpta* (Nees) Stapf	Silver finger grass	Grass	Indigenous	Absent	Present	Absent
Poaceae	*Echinochloa crus-galli* (L.) P.Beauv.	Cockspur grass	Grass	Alien	Present	Absent	Absent
Poaceae	*Eleusine coracana* (L.) Gaertn.	Goose grass	Grass	Indigenous	Present	Present	Present
Poaceae	*Elionurus muticus* (Spreng.) Kuntze	Wire lemon grass	Grass	Indigenous	Absent	Present	Absent
Poaceae	*Enneapogon scaber* Lehm.	Enneapogon	Grass	Alien	Present	Present	Present
Poaceae	*Eragrostis curvula* (Schrad.) Nees	Love grass	Grass	Indigenous	Present	Absent	Absent
Poaceae	*Eragrostis plana* Nees	Eragrostis	Grass	Indigenous	Present	Present	Present
Poaceae	*Lolium perenne* L.	Perennial ryegrass	Grass	Alien	Absent	Present	Absent
Poaceae	*Melinis repens* (Willd.) Zizka	Rose Natal grass	Grass	Indigenous	Absent	Present	Absent
Poaceae	*Adenochloa ecklonii* (Nees) Zuloaga	Bajiho	Grass	Indigenous	Absent	Present	Absent
Poaceae	*Trichanthecium natalense* (Hochst.) Zuloaga & Morrone	Natal buffalo grass	Grass	Indigenous	Absent	Present	Absent
Poaceae	*Panicum schinzii* Hack.	Land grass	Grass	Indigenous	Present	Absent	Absent
Poaceae	*Paspalum dilatatum* Poir.	Paspalum spp	Grass	Alien	Present	Absent	Absent
Poaceae	*Cenchrus geniculatus* Thunb.	Fountain grass	Grass	Indigenous	Absent	Present	Absent
Poaceae	*Sporobolus africanus* (Poir.) Robyns & Tournay	Rush grass	Grass	Indigenous	Absent	Present	Absent
Poaceae	*Nassella neesiana* (Trin. & Rupr.) Barkworth	Stipagrostis spp	Grass	Alien	Present	Absent	Absent
Poaceae	*Themeda triandra* Forssk.	Red oat grass	Grass	Indigenous	Present	Present	Present
Poaceae	*Urochloa panicoides* P.Beauv.	Panic liverseed grass	Grass	Indigenous	Present	Present	Present
Polygalaceae	*Polygala amatymbica* Eckl. & Zeyh.	Clump forming plant	Forb	Indigenous	Present	Absent	Absent
Portulacaceae	*Portulaca oleracea* L.	Pigweed	Forb	Alien	Present	Present	Present
Rubiaceae	*Richardia brasiliensis* Gomes	Tropical Mexican clover	Forb	Alien	Present	Present	Present
Scrophulariaceae	*Jamesbrittenia aurantiaca* (Burch.) Hilliard	Terracotta gazania	Forb	Indigenous	Absent	Absent	Absent
Solanaceae	*Datura stramonium* L.	Jimson weed	Forb	Alien	Present	Absent	Absent
Solanaceae	*Solanum retroflexum* Dunal	Earleaf nightshade	Forb	Alien	Present	Present	Absent
Solanaceae	*Solanum humile* Lam.	Flannel weed	Forb	Alien	Present	Present	Present
Urticaceae	*Urtica urens* L.	Dwarf nettle	Forb	Alien	Present	Absent	Absent
Verbenaceae	*Chascanum hederaceum* (Sond.) Moldenke	White trumpets	Forb	Indigenous	Present	Present	Present
Verbenaceae	*Verbena bonariensis* L.	Tall verbena	Forb	Alien	Present	Present	Present
Zygophyllaceae	*Tribulus terrestris* L.	Tack weed	Forb	Indigenous	Present	Absent	Absent

Table 6. Total number of all weed families and species (indigenous and alien) in maize fields and field margins

Totals	MF & M	MF	M
Families	31	25	25
All species	88	74	61
Indigenous species	48	35	34
Alien species	40	39	27

Note: MF: Maize fields; M: Field margins

Weed species composition of maize fields and margins

NMDS analysis showed separate groupings for maize fields and field margins in two-dimensional space. Clear clustering revealed that the field margins and maize fields were floristically distinct. Observable differences were verified by PERMANOVA ($p<0.001$) which confirmed that species composition differed significantly between maize fields and field margins (Figure 9).

NMDS ordinations furthermore revealed that some of the more distant Tsolo maize fields were positioned far right in terms of species composition explained by the distance of 60 km between Tsolo and Baziya sites. In contrast, the other three sites clustered closely together, showing broad similarity in composition. These three sites occurred within the same locality (no two sites were more than 6 km apart). Separation or grouping of quadrats from the same site were ascribed to pre-ploughing versus post-ploughing and seed-sowing surveys (Figure 10).

In field margins, there was a separation of plots per site based on weed species composition. The split observed for site-specific weed assemblages (circled in black; Figure 11) could be due to the distance between the sites, or a pre-ploughing versus post-ploughing and seed-sowing effects (herbicide drift).

Weed species diversity across maize fields and margins

A significantly higher number of weed individuals were recorded for field margins when compared to maize fields ($p<0.001$; Figure 12A). Conversely, species evenness was significantly higher for maize fields ($p=0.001$; Figure 12B), suggesting fewer species were dominating in maize fields compared to field margins. Overall, a low evenness value of less than 0.6 was recorded for both maize fields and field margins, suggesting that weed species did not occur at equal proportions in either maize fields or field margins. Simpson and Shannon diversity (Figure 12C, D) both showed a significantly higher value ($p=0.044$; $p=0.003$) for maize fields compared to field margins, suggesting that maize fields had a greater diversity of weed species. Diversity index values were generally low, at less than 1.5 for both maize fields and field margins, which suggested that these areas were generally poorly colonized due to annual disturbance. Total species (S) and Margalef's species richness (d) revealed no significant difference between maize fields and field margins ($p>0.05$).

Total weed individuals in maize fields were significantly higher in BM compared to MV ($p=0.007$; Figure 13A), whereas the other sites did not reveal significant differences in the total number of individuals (Figure 13A). For the remaining diversity indices (Figure 13B-D), significant differences were recorded only between MV and T, with a higher Simpson's index of diversity ($p=0.01$) and Shannon-Wiener diversity index ($p=0.01$) being recorded for the latter. Therefore, the maize field sites were considered of varying diversity. The irregular patterns observed may be ascribed to site specific management practices and other unknown abiotic factors.

No significant differences in terms of species richness and diversity were revealed between sites sampled in field margins ($p>0.05$). Consequently, field margin sites were considered equal in diversity, independent of site, but this must be noted with caution, since these reference sites were under-sampled (Figure 7B).

Discussion

Weeds are generally adapted to habitats that are disturbed by crop cultivation (Hadi et al. 2014). Different weed species are usually associated with a certain crop and always inhabit that specific cropland depending on the local climate and management practices (Gage et al. 2019; MacLaren et al. 2020). Furthermore, Botha et al. (2017) and Janse van Rensburg et al. (2020) reported that diversity of plants in Bapsfontein, Tarlton, Winterton, Belfast, and Reitz localities was lower inside maize and soybean fields than field margins, respectively. They also indicated that species assemblages form distinct plant communities in maize and soybean fields and field margins. Hence, field margins are rich in plant diversity because they are less transformed compared to maize fields.

Weed species such as *Cyperus esculentus*, *Commelina benghalensis*, and *Tagetes minuta* differed between maize fields and field margins because of different disturbance intensities, which could include ploughing and chemical applications (Botha et al. 2015). Hence, species that survive in the maize fields are those that colonize rapidly (Fried et al. 2020). In the margins, *Arctotheca calendula*, *Cynodon dactylon*, *Richardia brasiliensis*, *Sonchus nanus*, *Tagetes minuta*, and *Themeda triandra* had a higher mean abundance than in maize fields. This suggests that weed species can respond well to agricultural disturbance of margins in the absence of regular ploughing or herbicide applications, which regularly suppresses weed establishment within maize fields. Species with higher mean abundance in the maize fields included *Amaranthus viridis*, *Euphorbia prostrata*, *Dysphania carinata*, *Cyperus* sp., *Helichrysum griseolanatum*, and *Ipomoea purpurea*. This suggests that they have a rapid colonization trait, such as dormant seed, which allows them to rapidly invade or survive a ploughed or sprayed area. Therefore, different species react differently to the environment due to disturbance (Muller et al. 2021). Native grass species, such as *Themeda triandra* were more dominant in the field margins and nearly absent from the maize fields due to sensitivity to disturbance and herbicides.

Table 7. Similarity Percentage Analysis (SIMPER) of the average percentage dissimilarity of weed species contributing more than 5% to the dissimilarity between fields and margins of the four sites

Taxon	Average dissimilarity	Contribution %	Cumulative %	Mean abundance (1st)	Mean abundance (2nd)
a. Maize fields (MF) vs Margin (M)					
Richardia brasiliensis	32.08	34.17	34.17	18.5	1,410
Cynodon dactylon	25.65	27.33	61.49	74.9	942
Sonchus nanus	5.17	5.5	67	13.6	143
b. MF: MV vs BM					
Amaranthus viridis	20.19	21.8	21.8	7.28	309
Cynodon dactylon	11.36	12.27	34.08	99.1	99.6
Cyperus sp.	7.41	8.01	42.09	26.7	84.3
Helichrysum griseolanatum	6.58	7.11	49.2	191	6.43
Dysphania carinata	5.58	6.03	55.23	67.6	35.3
c. MF: MV vs MJN					
Cynodon dactylon	13.21	14.57	14.57	99.1	50.6
Helichrysum griseolanatum	9.64	10.64	25.21	191	45.3
Cyperus sp.	7.58	8.36	33.57	26.7	59.5
Ipomoea purpurea	7.41	8.16	41.74	49.3	74.3
Cotula carinatum	5.74	6.33	48.07	67.6	3.27
d. MF: MV vs T					
Helichrysum griseolanatum	10.13	10.64	10.64	191	71
Cynodon dactylon	9.63	10.11	20.76	99.1	9.07
Helichrysum asperum	6.37	6.69	27.45	1.71	103
Dysphania carinata	5.47	5.74	33.2	67.6	9.53
e. MF: BM vs MJN					
Amaranthus viridis	20.44	22.38	22.38	309	25.4
Cynodon dactylon	8.68	9.51	31.89	99.6	50.6
Cyperus sp.	8.63	9.45	41.35	84.3	59.5
f. MF: BM vs T					
Amaranthus viridis	18.6	19.82	19.82	309	27.7
Cyperus sp.	6.22	6.62	26.45	84.3	11.6
Helichrysum asperum	6.17	6.57	33.03	20.4	103
Cynodon dactylon	5.33	5.68	38.71	99.6	9.07
g. MF: MJN vs T					
Helichrysum asperum	7.26	7.82	7.82	18	103
Helichrysum griseolanatum	6.24	6.72	14.54	45.3	71
Cotula heterocarpa	6.19	6.66	21.21	66.7	54
Cyperus sp.	6.05	6.51	27.73	59.5	11.6
Cynodon dactylon	5.71	6.15	33.88	50.6	9.07
h. M: BM vs MJN					
Richardia brasiliensis	9.07	18.79	72.22	531	728
Helichrysum griseolanatum	3.14	6.51	78.73	1.6	181
Sonchus nanus	2.99	6.21	84.94	212	100
i. M: BM vs MV					
Cynodon dactylon	33.19	48.08	48.08	2,213	520
Richardia brasiliensis	19.9	28.82	76.9	531	1,883
Sonchus nanus	3.96	5.74	82.64	212	88.1
j. M: BM vs T					
Cynodon dactylon	40.8	52.16	52.16	2,213	0
Richardia brasiliensis	19.85	25.38	77.54	531	1,713
Sonchus nanus	6.23	7.97	85.51	212	207
k. M: MJN vs MV					
Richardia brasiliensis	23.12	39.94	39.94	728	1,883
Cynodon dactylon	18.04	31.17	71.11	1,223	520
Helichrysum griseolanatum	3.79	6.55	77.67	181	5.33
Amaranthus calendula	3.44	5.95	83.62	151	17.4
l. M: MJN vs T					
Cynodon dactylon	31.21	42.65	42.65	1,223	0
Richardia brasiliensis	24.98	34.14	76.79	728	1,713
Sonchus nanus	5.30	7.24	84.03	100	207
Amaranthus calendula	4.06	5.54	89.58	151	0
m. M: MV vs T					
Richardia brasiliensis	36.36	52.24	52.24	1,880	1,710
Cynodon dactylon	14.17	20.36	72.6	520	0
Sonchus nanus	6.44	9,26	81.86	88.1	207

Note: MV: Baziya Makaula; MJN: Baziya Jojweni; BM: Baziya Mission; T: Tsolo; Red: Indicates higher mean abundance

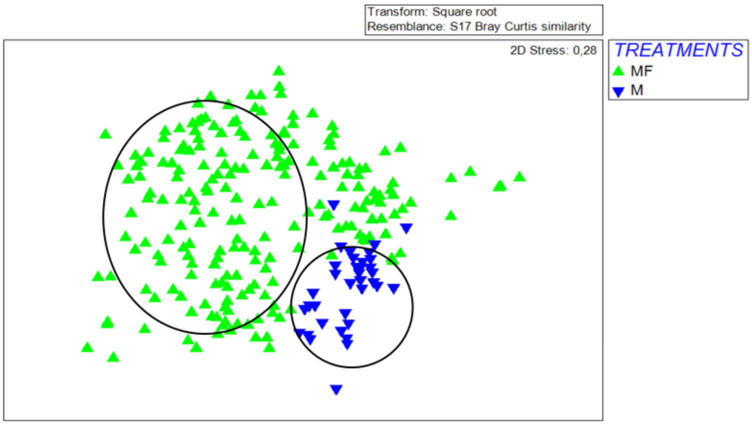

Figure 9. NMDS ordination of weed species assemblages across sampled sites for maize fields (MF) and margins (M)

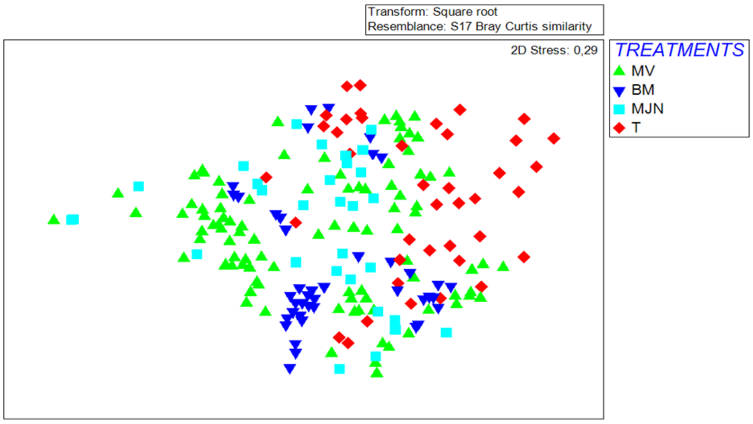

Figure 10. NMDS ordination of weed species assemblages across sampled sites. Baziya Mission (MV), Baziya Makaula (BM), Baziya Jojweni (MJN) and Tsolo (T)

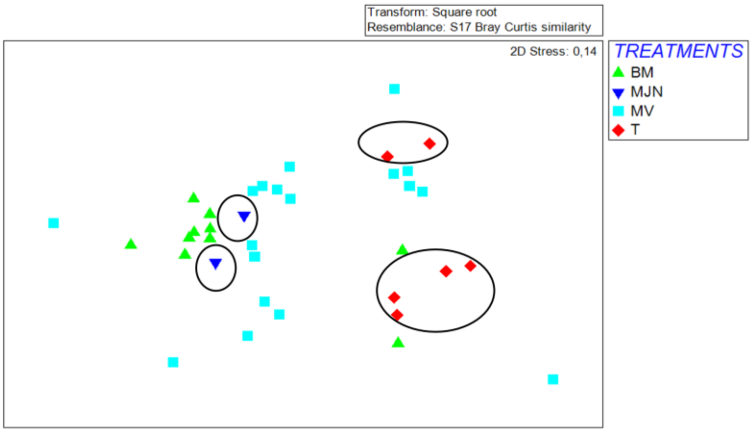

Figure 11. NMDS analysis for all weed species of the sampled field margins (M). Baziya Mission (MV), Baziya Makaula (BM), Baziya Jojweni (MJN) and Tsolo (T). Field margin samples in black are separated based on distance (MJN versus T) or due to pre- and post herbicide applications (T)

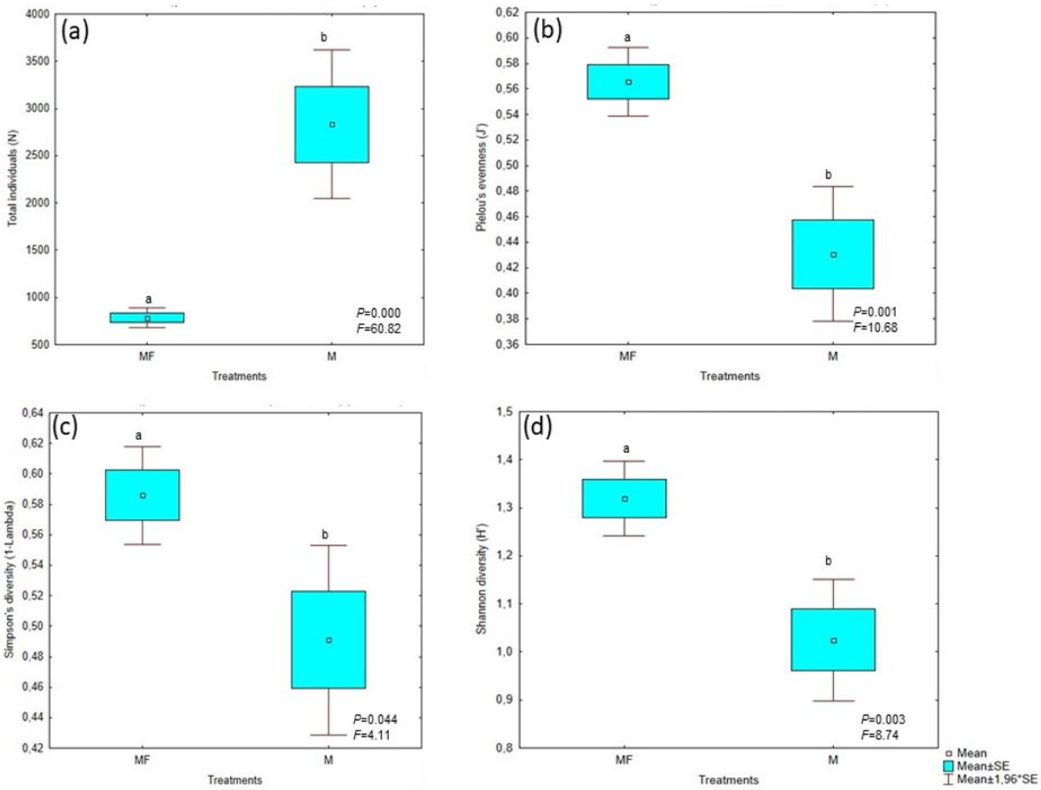

Figure 12. Comparisons of mean total weed individuals (A), Pielou's evenness (B), Simpson's index of diversity (C) and Shannon-Wiener diversity index (D) between maize fields (MF) and field margins (M). Significant differences (at p<0.05) are indicated by different letters

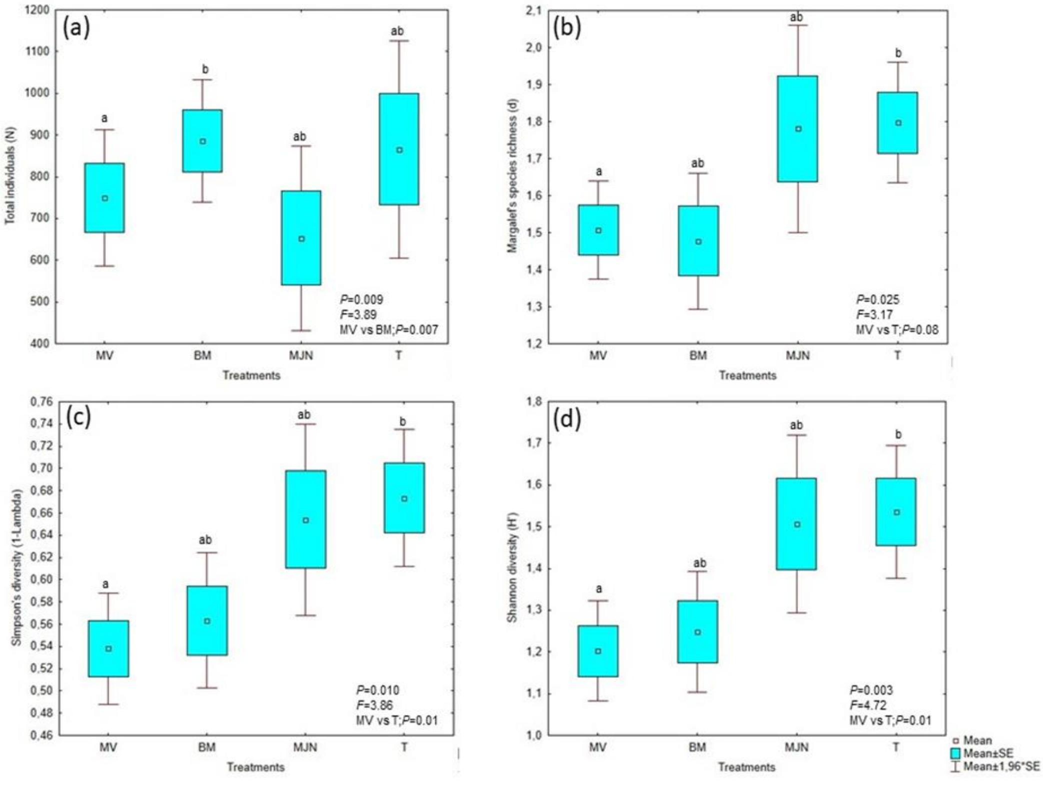

Figure 13. Comparison of mean weed individuals (A), Margalef's species richness (B), Simpson's index of diversity (C) and Shannon-Wiener diversity (D) across the different sites within maize fields. Baziya Makaula (MV), Baziya Mission (BM), Baziya Jojweni (MJN) and Tsolo (T). Significant differences (at p<0.05) are indicated by different letters

The dominance of *Cyperus* sp. at the Baziya Makaula and Tsolo sites, despite herbicide application, suggests that sedges are disturbance resistant due to underground propagules, and can avoid herbicide applications in the maize fields during dormancy (Peerzada 2017). Weed species that were dominant in field margins across sites were *Arctotheca calendula* in the MJN, *Cynodon dactylon*, and *Sonchus nanus* in BM and, *Richardia brasiliensis* and *Sonchus nanus* in T. *Cynodon dactylon* was found to be dominant in the maize fields and field margins of BM, suggesting that weeds have random adaptation to different disturbance regimes (Peerzada 2017). Weeds can also be cosmopolitan and adapted to the same disturbances, such as the occurrence of *Echinochloa crus-galli*, *Chenopodium album*, *Galinsoga parviflora*, and *Cirsium arvense* as dominant weeds in maize fields of Lublin, Poland (Sawicka et al. 2020). These species are also part of the weed flora of the Eastern Cape, but were not locally common in our study sites.

Examples of maize field-associated weeds in this study were *Amaranthus viridis*, *Cyathula prostrata*, *Cotula carinatum*, *Cynodon dactylon*, *Cyperus* sp., *Helichrysum asperum*, *H. griseolanatum*, *Ipomea purpurea*, *Richardia brasiliensis*, and *Sonchus nanus* (Table 7). This is in accordance with reports of weed species associated with maize crops by Botha et al. (2017) and Maseldzija and Dudic (2018). GrainSA (2015) has likewise reported weed species for the genera commonly found in this study, namely species of *Amaranthus*, *Cynodon*, *Cyperus*, *Erigeron (Conyza)*, and *Ipomoea*.

Giraldo et al. (2019) reported that in wheat and barley agroecosystems of Europe, 30% of weed species were also found in field margins. However, in this study, the weed species shared between maize fields and field margins were 53%, but there was only a slight nesting of weed species assemblages between maize fields and field margins due to disturbance intensity (ploughing and herbicides) (Figure 8). However, differences in weed species assemblages were also observed between sites, suggesting that local environmental factors and management practices drive a dissimilarity in weed species composition.

When sites were compared for maize fields only, some of the Tsolo fields were compositionally different from the other sites. This slight difference in weed species composition, compared to other sites, could be attributed to different environmental parameters (Siebert et al. 2020). In contrast, the other three sites (MV, BM, and MJN) showed broad similarity in composition among themselves and were also in closer proximity, suggesting similar environmental parameters (Sawicka et al. 2020). In field margins, there was a separation of plots per site based on weed species composition for BM and MV. Margins of Tsolo were substantially separated from MJN in terms of species composition suggesting the influence of climatic factors (Raza et al. 2019; Siebert et al. 2020), as there was no herbicide application or ploughing in field margins. This rejects the hypothesis that HT maize fields have similar weed species composition across sites for fields or their margins.

The results did support the second part of the hypothesis that weed species composition will differ between maize fields and field margins. There is a definite shift of weed species between maize fields and field margins. This would be expected considering the disturbance intensities in maize fields compared to field margins (Botha et al. 2015) and the dispersal and persistence traits of the species assemblages (Ferrero et al. 2017).

The main purpose of most agricultural systems is to achieve better yield production by reducing and/or completely eradicating weed species (Shafi 2018). Our findings showed that maize fields had significantly lower weed individuals, but higher evenness and diversity than the field margins (Figures 12 and 13). These effects are ascribed to agricultural practices that target and subdue weed species accumulation within maize fields. Hence, crop fields are unfavorable environments for most weed species because of high levels of agricultural disturbances involving weed management, such as ploughing, herbicide application, use of fertilizers and crop rotation (Hatfield and Prueger 2015; Reynolds et al. 2015). Chemical control of weed species has been shown to successfully reduce the abundance and diversity of weeds (Santín-Montanyá et al. 2013). It is also important to note that weeds often continue to be present and abundant in crop fields due to their pre-adaptive traits to intensive cropping systems (Botha et al. 2017), the dynamic nature of weeds (Batlla et al. 2020), management practices, including herbicide application, and shifts in weed species (Botha et al. 2017).

The maize fields had significantly higher evenness than field margins, despite being more heavily disturbed. This could be attributed to herbicide application in the fields which suppresses dominant weeds. This contrasted the findings of Janse van Rensburg et al. (2020), who found soybean crop fields to have significantly lower evenness than the boundary. In that instance, the factors that reduced evenness were chemical application and grazing disturbance. In the case of HT maize fields in the EC study, intensive selective grazing in field margins favours unpalatable species (Blair et al. 2018), which results in such species dominating and reducing the species evenness of these margins. It is important to consider such contrasting findings in weed science because it indicates that weeds inside fields do not necessarily originate from the margins (Blair et al. 2018).

Agricultural disturbance affects plant diversity in field margins due to grazing but also herbicide drift (Khan et al. 2017). The observed lower diversity in margins was also found in other studies, for example, Janse van Rensburg et al. (2020) reported lower plant diversity in the field margins adjacent to crop fields that were treated with herbicides. Schmitz et al. (2014) observed the same effect due to fertiliser drift from fields into the margin. Therefore, maize fields harbour a richer diversity of weeds than the margins, which support the hypothesis that weed diversity will differ between maize fields and field margins. Moreover, weed diversity between maize fields differed significantly which does not support the hypothesis that all fields of a region will have similar weeds.

In conclusion, HT maize systems had dissimilar weed composition and diversity across fields, and between maize fields and field margins. In response to agricultural disturbance, maize fields had a lower abundance of weeds, but higher diversity than field margins. Weed species assemblage composition differed between maize fields and field margins. The difference between maize fields and field margins could be ascribed to differences in management practices, as the field margins are less disturbed compared to maize fields that experience disturbance in various ways, such as herbicide application and ploughing, and margins by intensive grazing and herbicide drift. There is a large overlap in weed species of maize fields and field margins, but fields have a higher total number of weeds and more alien weed species, suggesting that weed species can colonize and persist in the maize fields despite herbicide applications. Three families that contributed the most weed species were Asteraceae, Fabaceae, and Poaceae. Weed species contributing most to the dissimilarity of >5% between maize fields included *Amaranthus viridis, Dysphania carinata, Cotula heterocarpa, Cynodon dactylon, Cyperus* sp., *Helichrysum asperum, Ipomea purpurea,* and field margins were characterized by *Helichrysum griseolanatum, Richardia brasiliensis,* and *Sonchus nanus*. Knowledge gained from our study will benefit maize farmers and future researchers working on weeds in HT maize crops of the Oliver Tambo District Municipality, and in Sub-Saharan Africa, when it comes to the development, implementation and prioritizing of various herbicide-based weed management protocols and measures toward ensuring maximum crop productivity. It is important to remember that poor management practices can lead to herbicide resistance traits developing in weeds over time.

ACKNOWLEDGEMENTS

We would like to thank the Mthatha GrainSA office personnel, the chieftaincy, and farmers of Baziya, and the community and farmers of Tsolo for allowing us access to their farms during entire sampling seasons. Appreciation to field assistants and Fhatani Ranwashe from South African National Biodiversity Institute (SANBI) for mapping the study area. Many thanks to the SANBI Kirstenbosch Compton Herbarium and AP Goossens Herbarium at the North-West University for plant identification and specimen storage. National Research Foundation (NRF), SANBI and the North-West University (Potchefstroom) provided funding.

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