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Diversity patterns of plants and arthropods in soybean agroecosystems in the grassland biome of South Africa

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Abstract. *Janse van Rensburg PD, Siebert SJ, Masehela T, Ellis S, Van den Berg J. 2020. Diversity patterns of plants and arthropods in soybean agroecosystems in the grassland biome of South Africa. Biodiversitas 21: 5559-5570.* Soybean is widely cultivated in the grassland biome of South Africa (ca. 800 000 ha per annum). Yet the possible effects that large-scale cultivation of soybean has on biodiversity in adjacent habitat are not fully understood. This study aimed to describe the plant and arthropod species assemblages and diversity patterns within these soybean agroecosystems. Surveys were conducted inside soybean fields, field boundaries (transition zones between soybean fields and adjacent habitat), and adjacent pasture. An adapted D-vac was used to sample arthropods in the different zones, while plant surveys were conducted by means of fixed width (2 m) line transect. A total of 320 plant species (4910 specimens) and 373 arthropod morpho-species (9216 specimens) were recorded. Soybean fields had significantly lower plant and arthropod diversity than the adjacent habitats. Plant species diversity was similar in the field boundary and adjacent pasture. Significantly higher species richness and abundance of arthropods were found in the boundary than the pasture. These results show that the cultivation of soybean and the associated agricultural practices had no adverse effects on biodiversity patterns in the adjacent habitats. However, the boundary dominated by alien plant species did contain a significantly different plant species composition from the pasture. This difference was also mirrored by unique assemblages of arthropods. This suggests that disturbance resulting from soybean cultivation contributed to species losses and gains that maintained diversity in the field boundary but changed its plant and arthropod species composition. No effect was found in the pasture beyond the boundary (> 50 m). High diversity, but unique species assemblages of plants and arthropods in the boundary and pasture suggest that these habitats may have important conservation value in soybean agroecosystems by supporting ecosystem functions and services.

Keywords: Agriculture, biodiversity, ecosystem services, field boundary, species richness

INTRODUCTION

Plants and arthropods are key components to ecosystem function and stability. Plant material may be browsed by herbivores, while pollen and nectar sustain pollinators and supplement the diet of entomophagous arthropods, and plant structures provide shelter to various organisms (Duru et al. 2015; Kaiser et al. 2017). In agricultural habitats plant diversity is important for erosion control, maintenance of soil fertility, buffering the movement of agrochemicals to natural habitats, and climate regulation (Gaba et al. 2015; Isbell et al. 2017). Arthropods serve as useful bioindicators of disturbance due to their short generation time and rapid response to environmental change (Ghannem et al. 2018; Menta and Remelli 2020). As consumers, arthropods comprise many important functional groups including herbivores, pollinators, detritivores, predators, and parasitoids.

South Africa’s biodiversity is facing increasing pressure from anthropogenic activities, habitat loss, species exploitation, pollution, climate change, and invasive alien species (Skowno et al. 2019). Intensive agriculture brings about the destruction and fragmentation of natural ecosystems and may result in loss of biodiversity by substituting it with domesticated animals and crops (Duru et al. 2015). This gives rise to an ecosystem for human food provision that is not capable to perform all required ecosystem services (Deutsch et al. 2013). These systems are highly reliant on human intervention and, in some instances, also on the use of agrochemicals (Bommarco et al. 2013) which may result in further degradation of remaining natural habitat through agrochemical drift (Felsot et al. 2011; Hahn et al. 2015).

The agricultural landscape in South Africa allows for both small scale (often informal) and large scale (commercial) agriculture. The latter allows for large scale production, with a market-orientated focus, and soybean falls within these criteria as it is one of the most economically important legumes in the world (DAFF 2018). Soybean provides good-quality vegetable protein to both the human and animal diet, and serves as a key ingredient for numerous chemical products. Agricultural policies that enable the use of transgenic herbicide-tolerant crops, and the benefits of crop rotation systems of soybean with maize, facilitate the continued expansion of soybean cultivation in South Africa (Dlamini et al. 2014). Soybean cultivation has increased significantly over the past 20 years, moving from an annual average of about 71 000 ha to 687 300 ha (DAFF 2018). In the 2018/2019 growing season, approximately 787 000 ha of soybean was planted in South Africa, of which 95% was genetically modified to be herbicide-tolerant (DAFF 2019; ISAAA 2018). Given the current soybean production rates and projected increases in the future, it is important to understand any possible effects that large-scale cultivation of soybean might have on biodiversity, in particular, for habitats adjacent to where soybean is grown.

In this study, we gathered baseline data to interpret current plant and arthropod diversity patterns and species assemblages that are associated with herbicide-tolerant soybean agroecosystems in the grassland biome of South Africa. Invasive weed species, application of agrochemicals, and tillage practices contribute to a high level of seasonal disturbances in crop fields (Felsot et al. 2011; Plaza et al. 2015). Firstly, we hypothesize that soybean fields have lower diversity of plants and arthropods than adjacent habitats. Disturbances associated with crop fields may also affect the field boundary (zone directly adjacent to the crop) (Pryke and Samways 2012; Botha et al. 2015; Hahn et al. 2015). Therefore, the field boundary was also compared with the adjacent pasture in terms of species diversity and composition and we hypothesize that the boundary will have a lower diversity of plants and arthropods due to possible disturbances arising from adjacent crop fields. Species data along the disturbance gradient is representative of current agricultural practices involving herbicide-tolerant cultivars. Lastly, we hypothesize that the current practices of tilling and herbicide drift act as filters that allow tolerant and resistant non-crop plant species to form new assemblages within highly disturbed crop fields and moderately disturbed field boundaries. This change in plant species composition along the gradient results from a temporal new habitat and food sources that could select for new assemblages of arthropods. Having a clear understanding of prevailing conditions will allow for long term monitoring to determine whether agricultural practices associated with herbicide-tolerant species can alter the plant and arthropod diversity in crop fields and margins. This is important to assess in line with prescribed national or regional biodiversity assessment to ensure that important ecosystem services are not lost from these dynamic zones within the agroecosystem – for example, the National Biodiversity Assessment, conducted every five years in South Africa. The objective of this research is to provide insight into the plant and arthropod diversity patterns and species assemblages that are associated with soybean agroecosystems in South Africa.

MATERIALS AND METHODS

Study localities

Five localities (Figure 1) were selected in the major soybean-producing regions of South Africa (Dlamini et al. 2014). At each locality, two sites were selected for surveys. Soybean was used in crop rotation systems with maize at all sampling sites. Farm fences and small dirt roads often formed anthropogenic boundaries between soybean fields and field margins. Livestock grazing (cattle and sheep) was common in field margins surrounding crop fields. Sample sites were selected to include a range of environmental variables associated with soybean agroecosystems in general (Table 1).

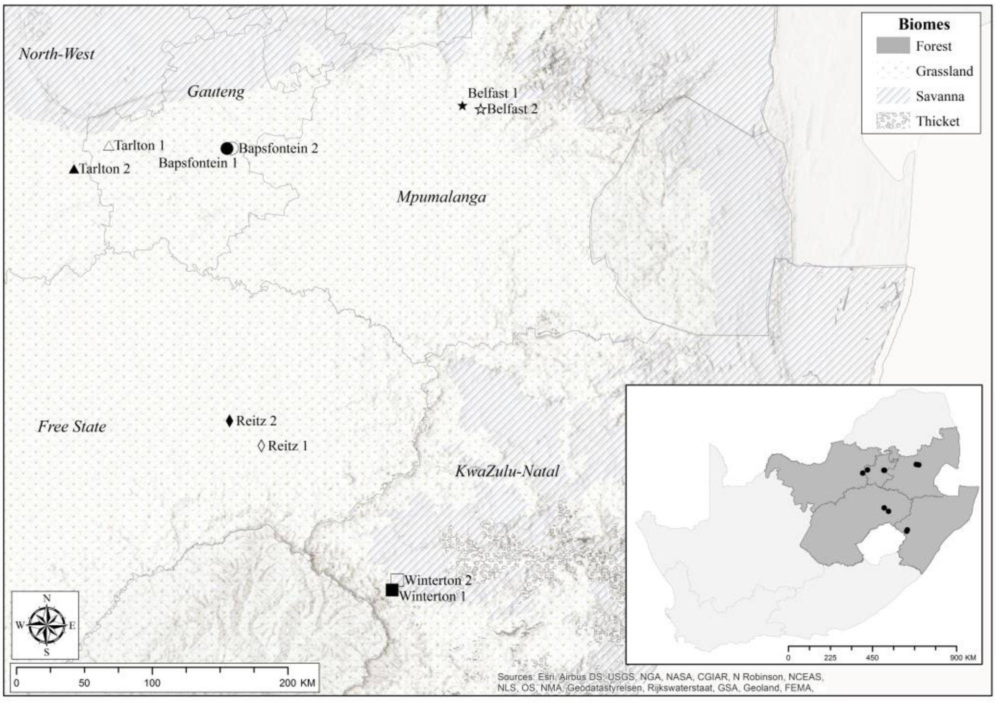

Figure 1. The five study localities in relation to the nearest town

Table 1. Vegetation units, altitude and climatic conditions of the five localities (Mucina and Rutherford 2006)

Localities	Altitude (m asl.)	MAP (mm)	MAT (°C)	MFD	Vegetation unit
Bapsfontein	1300-1635	654	15.8	28	Rand Highveld Grassland
Tarlton	1420-1760	662	14.8	41	Soweto Highveld Grassland
Winterton	1040-1440	836	16.2	20	Northern KwaZulu-Natal Moist Grassland
Belfast	1520-1780	726	14.7	32	Eastern Highveld Grassland
Reitz	1380-1740	634	14.4	50	Eastern Free State Clay Grassland

MAP – Mean annual precipitation; MAT – Mean annual temperature; MFD – Mean number of frost days

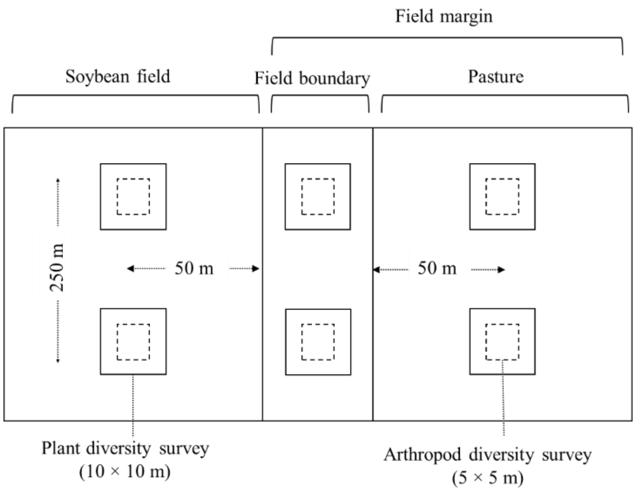

Figure 2. Transect and sampling plot layout at each of the ten sites

Experimental layout

At each locality, two sites were selected. At each site, a soybean field surrounded by pasture was chosen, and two transects (along a soybean field-boundary-pasture gradient) were placed 250 m apart (Figure 2). In each transect, three sampling plots were placed, one in each of the zones: the soybean field, field boundary, and pasture (Figure 2). Plots were placed 50 m apart, with the first plot situated 50 m within the soybean field, the second within the field boundary (30 m wide zone in the crop margin with a high level of anthropogenic disturbance), and the third plot, 50 m into the adjacent pasture. The field boundary width was taken as 30 m as determined for similar agroecosystems in the grassland biome of South Africa (Botha et al. 2015). Sampling plots were 5 m × 5 m (25 m^2) in size for arthropod sampling, sampled first, and then expanded to 10 m × 10 m (100 m^2) for the plant diversity surveys as per previous studies (Botha et al. 2015). Surveys in Bapsfontein and Tarlton were conducted in late summer 2018, and surveys at Winterton, Belfast, and Reitz were conducted in late summer 2019.

Arthropod sampling

The target arthropod guild for this study was plant-dwelling species. Surveys were conducted during the flowering stage of the crop. Previous studies on insect diversity and arthropod succession on soybean during this period have shown it to be an ideal period to sample a comprehensive arthropod community (Carner et al. 1974; Shelton and Edwards 1983). This also ensured that all the soybean plants across locations were at a similar growth stage during the survey.

Arthropods were collected through suction sampling by means of an adapted D-vac method (Dietrick et al. 1960). Inside the pasture and field boundary plots, the D-vac suction machine was moved in an up and down motion to collect arthropods that occurred on lower and upper foliage of plants. Inside the soybean plots, the suction machine was moved slowly over both the soybean plants and other plant species (weeds) that were present in the crop while walking between the plant rows inside the demarcated plot. Although the study focussed on plant-dwelling arthropods, soil-dwelling arthropods occurring near the base of the plant were also prone to collection.

The sample collected in each plot were placed in a plastic bag and frozen to preserve the contents. The contents of each bag were then sorted in the laboratory to separate the arthropods from plant debris, after which arthropods were preserved in bottles containing 70% alcohol. Arthropods were classified up to morpho-species level with the aid of literature such as Scholtz and Holm (2012), Dippenaar-Schoeman (2014), and Picker et al. (2019). Care was taken to ensure morpho-species were the same across all localities. The number of morpho-species, as well as the abundance of each morpho-species, was determined for each plot.

Vegetation sampling

After the arthropods were sampled, all plot sizes were increased for the vegetation sampling. The approach of Botha et al. (2015) was followed. Five line-transects of 10 m each were placed, with the first transect 1 m inside the sampling plot and the others spaced 2 m apart and parallel to each other. The closest grass, forb, and shrub species were identified and recorded at intervals of 1 m along the 10 m transect. If no plants occurred within 0.5 m before or after the point, bare ground was recorded. Plants were identified to species level and species names follow Germishuizen et al. (2006).

Data analysis

To test whether significant differences in plant and arthropod communities existed between the different zones, PERMANOVA was performed in PRIMER 6 (2012) using abundance data. All PERMANOVA analyses were performed with 999 permutations using Bray-Curtis similarity and type III sums of squares.

To depict how different points compared in terms of plant and arthropod species composition and to assess the importance of certain environmental variables (altitude, MAT, MAP, latitude, and longitude), and land-use intensity in determining plant and arthropod species assemblages, CCA was applied in PAST (Hammer et al. 2001). Land-use intensity was used as an indicator of landscape-level anthropogenic disturbance. Land-use in a 1 km radius surrounding each sample plot was observed with satellite images and measurement tools using Google Maps. Three land-use types were recorded. These were croplands, buildings and settlements, and roads and farm fences. A land-use intensity score was calculated around each sample plot for each land-use type (Table 2). The scores of the three land-use types were summed to acquire a land-use intensity rating around each sample plot.

To determine indicator species for each zone, IndVal was applied in R software (Roberts 2016). Species richness, abundance, and diversity indices (Margalef's species richness, Shannon-Wiener diversity index, Pielou's Evenness, and Simpson's diversity index) were calculated to compare diversity trends of plants and arthropods across the disturbance gradient and between localities. Index values were calculated with PRIMER 6 (2012). To test for significant differences in index values along the soybean field-field margin gradient, HLM was performed in SPSS (Hancock and Mueller 2010). Transects were specified as subject (ID) to account for the nestedness of transects within localities. The covariance structure was specified as unstructured. Effect sizes (Cohen's *d*) were used to express practical significance between sampling points where residual as well transect variance were taken into account in the calculation of the effect sizes (Ellis and Steyn 2003).

RESULTS AND DISCUSSION

Rarefaction curves indicated sufficient sampling effort for both the plant and arthropod diversity surveys (Figure 3). The plant diversity survey recorded 4910 individuals representing 320 species and 52 plant families. The lowest number of species (39) was recorded inside soybean fields, while 127 and 246 species were recorded in field boundaries and pasture respectively. The Poaceae, Asteraceae, and Fabaceae were the best-represented families and collectively accounted for 54% of the total number of species. Collectively, 59 alien plant species were recorded, representing 18% of all the recorded plant species. A total of 3053 arthropod specimens, 373 morpho-species, and 97 families were recorded. The soybean field contained the lowest number of morpho-species (170), compared to the field boundary (280) and pasture (256). Fifteen arthropod orders were represented with the most significant contributions from Hemiptera, Coleoptera, Diptera, Araneae, Hymenoptera, and Thysanoptera.

Plant species composition

PERMANOVA revealed that the plant species composition differed significantly between the soybean field, field boundary, and pasture (Table 3).

Table 2. Scoring system to estimate the intensity of a land-use within a 1-km radius around a sample plot

Score	Description
8	Frequent presence of land-use in area. Sample plot completely surrounded by land-use.
6	Frequent presence of land-use in area. Sample plot surrounded by land-use and natural habitat.
4	Occasional and scattered presence of land-use in area. Close proximity to sample plot.
2	Occasional and scattered presence of land-use in area. Distant from sample plot.
0	Land-use not present.

Table 3. Results for PERMANOVA pair-wise tests indicating significant separations between treatment zones based on plant species composition

Treatment	t-value	P-value
Soybean field and Field boundary	2.762	0.001*
Soybean field and Pasture	3.498	0.001*
Field boundary and Pasture	2.852	0.001*

Note: * indicate significant separations at $p<0.05$

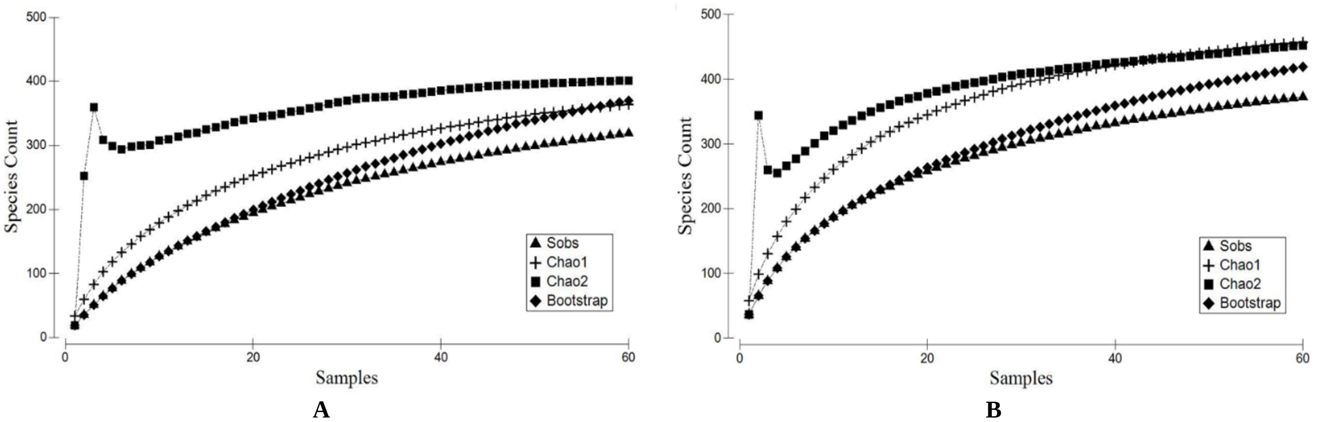

Figure 3. Rarefaction curve for the total plant (A) and arthropod (B) samples, with species richness estimates based on all species observed (Sobs), number of rare species (Chao 1), presence/absence data (Chao 2), and proportion of quadrants containing each species (Bootstrap)

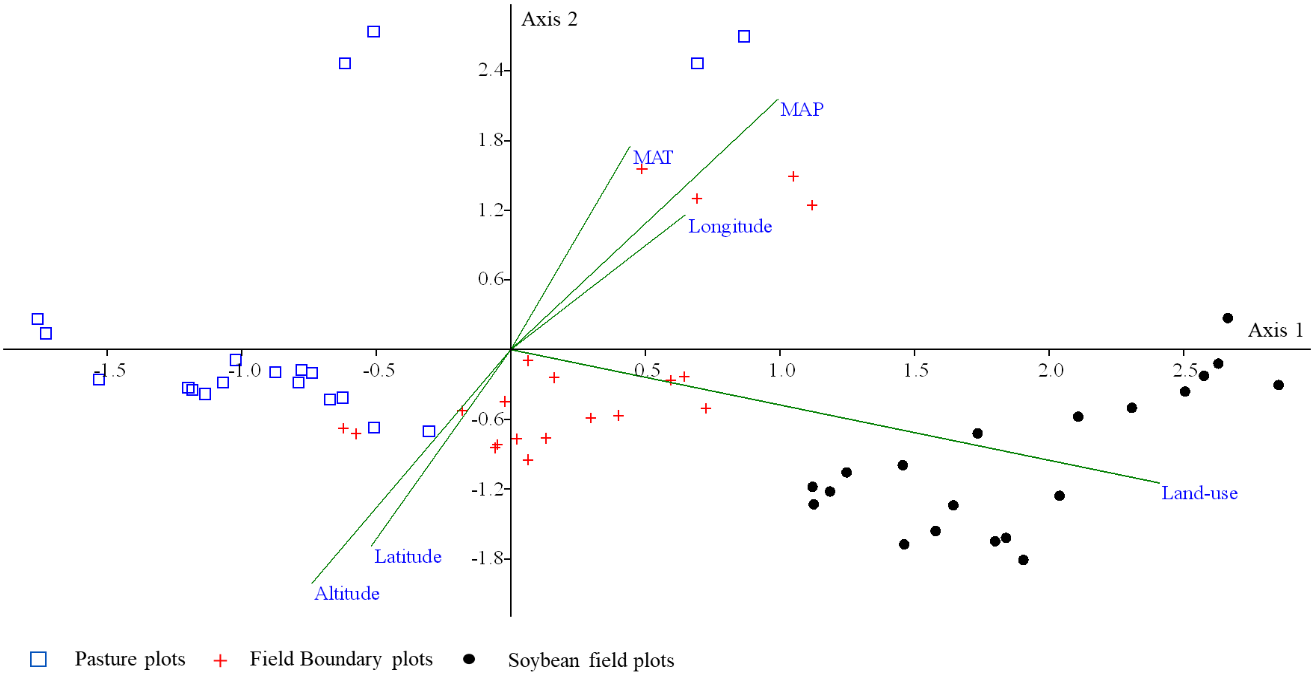

Figure 4. CCA of all the localities showing correlation of environmental variables with plant sample plots. Each symbol represents the weighted average of one plot in relation to environmental variables. The environmental variables were altitude, latitude, longitude, mean annual precipitation (MAP), mean annual temperature (MAT), and land-use intensity

The CCA indicated that land-use intensity was strongly correlated with axis 1, while MAP and altitude were strongly correlated with axis 2 (Figure 4; Table 4). The most important factor relating to plant species assemblages was land-use intensity which separated the different zones at a local scale. At a regional scale, MAP and altitude, and to a lesser extent MAT, separated the Winterton locality from other localities. Plant species composition of field boundary and pasture plots at Winterton was correlated with high annual precipitation and temperature. Species composition at the other localities showed strong positive correlations with altitude.

Indicator species analysis revealed five indicator plant species for the soybean field, 19 for the field boundary, and 36 for the pasture. The top 10 indicator species are listed in Table 5. Alien weeds were dominant in soybean fields (80%) and field boundaries (60%) while all the indicator species for the pasture were indigenous (Table 5). Forbs were dominant among the indicator species of soybean fields (80%) and field boundaries (50%) while grasses were dominant in the pasture (70%).

Plant diversity patterns

There were significant interaction effects between locality and zone for all diversity indices, indicating that not all localities reacted similarly (Table 6). This difference occurred mainly in the Reitz locality where lower diversity was observed in the pasture compared to the field boundary, whereas the pasture from other localities tended to be marginally more diverse than the boundary.

HLM revealed that soybean fields had significantly lower plant abundance and diversity index values than both the field boundary and pasture (Table 7). However, no significant differences were recorded between the boundary and pasture

Arthropod species composition

PERMANOVA revealed that the three zones had significantly different arthropod species assemblages (Table 8).

The CCA for arthropod sample plots showed strong correlations of land-use intensity with both axis 1 and 2 (Figure 5; Table 9). Longitude and MAP had relatively strong correlations with axis 2. The most important factor relating to arthropod species assemblages was land-use intensity which separated the different treatment zones at a local scale. At a regional scale, arthropod species assemblages at the Winterton and Belfast sites were correlated with high MAP and more eastern longitude, while species assemblages at the Bapsfontein site were correlated with low MAP and a more western longitude.

There were 13 arthropod indicator morpho-species for soybean fields, 21 for the field boundaries, and 13 for the pasture. The top 10 indicator species for each zone are listed in Table 10. Indicator species for the soybean field were mostly phytophagous, with only one parasitoid species (Tachinidae MS 4). The boundary and pasture had higher numbers of parasitoid and predator indicator species compared to soybean fields, for example, crab spiders (Araneae: Thomisidae), lady beetles (Coleoptera: Coccinellidae), and chalcid wasps (Hymenoptera: Chalcidoidea).

Table 4. Correlations of ordination axes with environmental variables and eigenvalues and percentage variance explained for canonical correspondence analysis of plant species assemblages at all localities

Variable	Axis 1	Axis 2
Land-use intensity	0.804	-0.382
Altitude	-0.247	-0.563
Latitude	-0.173	-0.563
Longitude	0.216	0.387
Mean annual precipitation	0.331	0.719
Mean annual temperature	0.148	0.584
Eigenvalue	0.651	0.565
% variance explained	27.78	24.07

Table 6. HLM results for the total plant sample indicating significant interaction effects between locality and zone (field, boundary, and pasture)

Diversity indices	Locality*zone interaction effect	
	F-value	P-value
Species Richness	1.872	0.095
Abundance	1.782	0.113
Margalef Species Richness	2.572	0.025*
Shannon-Wiener Diversity	4.158	0.001*
Pielou's Evenness	4.66	0.001*
Simpson Diversity Index	7.619	<0.001*

Note: * indicate significant interaction effect at p<0.05.

Table 5. Highest indicator values for plant species in soybean fields, field boundaries, and pasture according to IndVal analysis

Soybean field				Field boundary				Pasture			
Species	IndVal	Freq	P-value	Species	IndVal	Freq	P-value	Species	IndVal	Freq	P-value
Cyperus esculentus L.	0.446	31	0.007	*Eleusine coracana* (L.) Gaertn	0.656	30	0.001	*Eragrostis curvula* (Scrhad.) Nees	0.536	25	0.001
Commelina benghalensis L.	0.393	21	0.009	*Bidens pilosa* L.	0.600	12	0.001	*Themeda triandra* Forssk.	0.526	12	0.001
Oxalis latifolia Kunth	0.297	7	0.005	*Cynodon dactylon* (L.) Pers.	0.597	25	0.001	*Eragrostis chloromelas* Steud.	0.463	17	0.002
Zea mays L.	0.200	4	0.026	*Amaranthus hybridus* L.	0.549	22	0.001	*Eragrostis racemosa* (Thunb.) Steud.	0.450	9	0.001
Dutura ferox L.	0.185	5	0.041	*Paspalum dilatatum* Poir	0.536	12	0.001	*Setaria sphacelata* (Schumach.) Stapf & C.E.Hubb. ex M.B.Moss	0.450	9	0.001
---	---	---	---	*Tagetes minuta* L.	0.477	13	0.001	*Eragrostis plana* Nees	0.438	20	0.002
---	---	---	---	*Setaria pallida-fusca* (Schumach.) Stapf & C.E. Hubb.	0.400	8	0.002	*Senecio coronatus* (Thunb.) Harv.	0.400	8	0.001
---	---	---	---	*Conyza bonariensis* (L.) Cronquist	0.391	20	0.003	*Brachiaria serrata* (Thunb.) Stapf	0.400	8	0.001
---	---	---	---	*Bidens formosa* (Bonato) Sch.Bip.	0.350	7	0.001	*Selago densiflora* Rolfe	0.381	9	0.003
---	---	---	---	*Panicum Schinzii* Hack.	0.342	8	0.005	*Oxalis obliquifolia* Steud. ex A. Rich.	0.345	10	0.003

Note: IndVal: Indicator value. Frequency refers to the number of survey plots the species were recorded from

Table 7. HLM results for the total plant sample. Mean value measures are given for the soybean field, field boundary, and pasture

Diversity indices	Means			Residual variance	Transect variance	F-value	P-value
	Soybean	Boundary	Pasture				
Species richness	6.26^a	20.58^b	32.03^b	14.926	0	184.26	<0.001*
Abundance	30.83^a	89.15^b	104.56^b	91.648	0	276.99	<0.001*
Margalef's species richness	1.58^a	4.37^b	6.66^b	0.649	0	160.81	<0.001*
Shannon-Wiener diversity index	1.26^a	2.55^b	2.95^b	0.066	0	178.30	<0.001*
Pielou's evenness	0.76^a	0.85^b	0.87^b	0.006	0	8.40	0.001*
Simpson diversity index	0.67^a	0.90^b	0.93^b	0.007	<0.001	107.37	<0.001*

Note: Means with different subscript symbols differed practically according to effect sizes (d ≥ 0.5). * indicate statistical significance at P < 0.05

Arthropod diversity patterns

At the Bapsfontein sites, species evenness was highest in the soybean field while at other sites, evenness was lower inside the crop compared to the margin. This resulted in significant interaction effects between locality and zone for Pielou's Evenness (Table 11). All other species diversity parameters had no significant interaction effects between locality and zone (field, boundary and pasture). This indicated that arthropod diversity at all localities reacted similarly along the sampling gradient (Table 11).

Table 8. Results for PERMANOVA pair-wise tests indicating significant separations between treatment zones based on arthropod species composition

Treatment	T-values	P-value
Soybean field and Field boundary	2.506	0.001*
Soybean field and Pasture	2.699	0.001*
Field boundary and Pasture	1.435	0.002*

Note: * indicate significant separations at p<0.05.

Table 9. Correlations of ordination axes with environmental variables and eigenvalues and percentage variance explained for canonical correspondence analysis of arthropod species assemblages at all localities

Variable	Axis 1	Axis 2
Land-use intensity	-0.694	0.660
Altitude	0.155	0.083
Latitude	0.168	0.366
Longitude	-0.193	-0.515
Mean annual precipitation	-0.262	0.421
Mean annual temperature	0.039	0.228
Eigenvalue	0.343	0.319
% variance explained	25.63	23.80

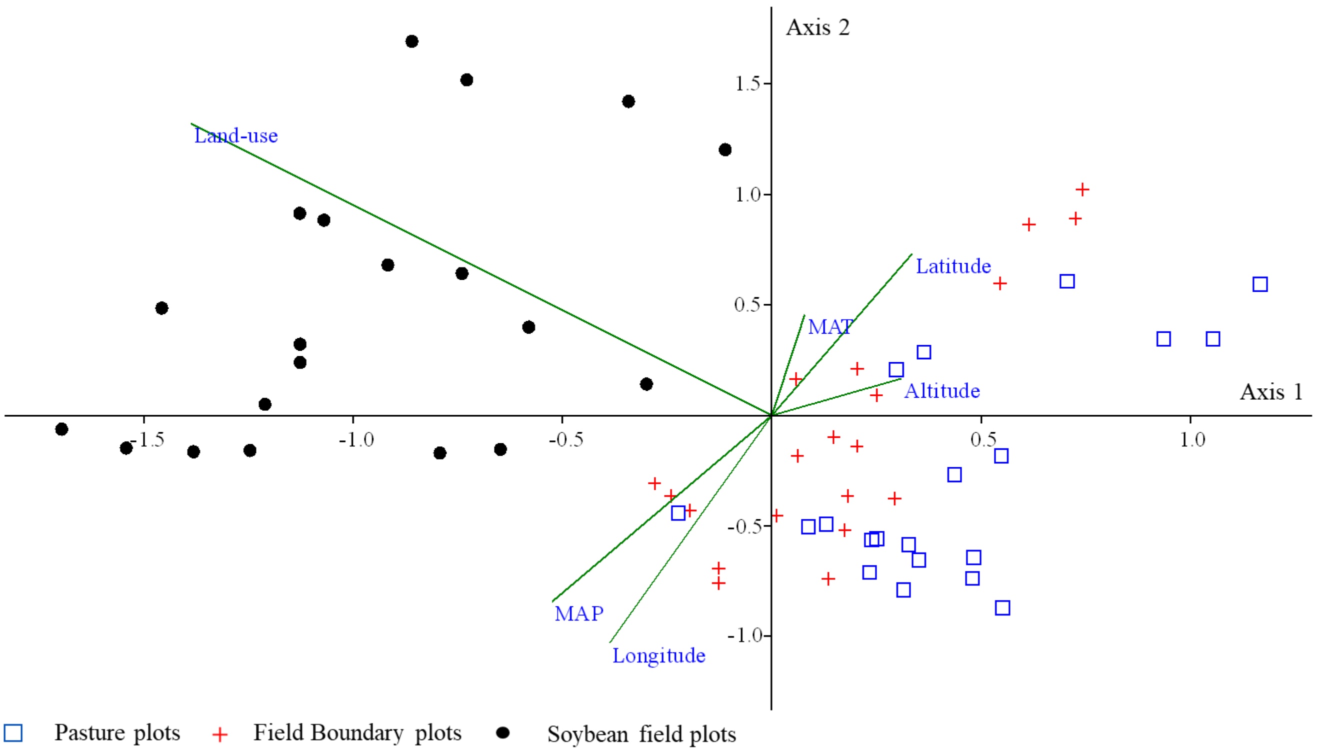

Figure 5. CCA of all the localities showing correlations of environmental variables with arthropod sample plots. Each symbol represents the weighted average of one plot in relation to environmental variables. The environmental variables were altitude, latitude, longitude, MAP, MAT, and land-use intensity

Table 10. IndVal analysis representing the ten indicator morpho-species with the highest indicator values for the soybean field, field boundary, and pasture

Soybean field				Field boundary				Pasture			
Morpho-species	IndVal	Freq	P-value	Morpho-species	IndVal	Freq	P-value	Morpho-species	IndVal	Freq	P-value
Thysanoptera MS 6	0.700	14	0.001	Melyridae MS 1	0.696	27	0.001	Formicidae MS 1	0.532	31	0.001
Tachinidae MS 4	0.685	22	0.001	Lygaeidae MS 1	0.590	29	0.001	Chrysomelidae MS 4	0.488	11	0.001
Pentatomidae MS 2	0.580	13	0.001	Chloropidae MS 1	0.467	37	0.001	Chalcidoidea MS 16	0.465	21	0.001
Chrysomelidae MS 2	0.503	24	0.003	Cicadellidae MS 1	0.408	37	0.024	Mycetophilidae MS 2	0.442	45	0.013
Cicadellidae MS 13	0.472	25	0.012	Acrididae MS 1	0.403	31	0.027	Cicadellidae MS 3	0.406	21	0.011
Noctuidae MS 3	0.450	9	0.001	Chalcidoidea MS 14	0.392	32	0.016	Cicadellidae MS 12	0.330	16	0.007
Nymphalidae MS 1	0.450	9	0.001	Lygaeidae MS 5	0.385	24	0.010	Anthomyiidae MS 1	0.320	9	0.002
Miridae MS 4	0.389	9	0.001	Coccinellidae larva MS1	0.349	15	0.008	Anthicidae MS 5	0.280	16	0.032
Thysanoptera MS 12	0.350	7	0.001	Cicadellidae MS 10	0.317	15	0.008	Thomisidae MS 2	0.255	11	0.038
Miridae MS 1	0.324	16	0.006	Cicadellidae MS 8	0.316	19	0.030	Fulgoridae MS 1	0.250	5	0.012

Note: IndVal: Indicator value. Frequency refers to the number of sample plots the species was recorded from

Table 12. HLM results for the total arthropod sample. Mean value measures are given for the soybean field, field boundary and pasture

Diversity indices	Means			Residual variance	Transect variance	F-value	P-value
	Soybean	Boundary	Pasture				
Species Richness	27.542^{a}	48.146^{b}	39.2^{c}	68.639	20.840	25.633	<0.001*
Abundance	104.586^{a}	194.191^{b}	148.904^{c}	3636.918	982.840	10.604	<0.001*
Margalef's Species Richness	5.729^{a}	9.001^{b}	7.701^{c}	1.618	0.670	26.940	<0.001*
Shannon-Wiener Diversity Index	2.622^{a}	3.139^{b}	3.133^{b}	0.103	0.061	12.942	<0.001*
Pielou's Evenness	0.828^{a}	0.847^{ab}	0.864^{b}	0.004	0.002	1.468	0.250
Simpson Diversity Index	0.895^{a}	0.930^{b}	0.939^{b}	0.004	0.002	4.941	0.016*

Note: Means with different subscript symbols differed practically according to effect sizes ($d \geq 0.5$). * indicate statistical significance at $P < 0.05$

Table 11. HLM results for the total arthropod sample indicating significant interaction effects between locality and treatment zone

Diversity indices	Locality*zone interaction effect	
	F-value	P-value
Species Richness	1.64	0.167
Abundance	1.45	0.225
Margalef's Species Richness	1.605	0.179
Shannon-Wiener Diversity	1.862	0.12
Pielou's Evenness	4.041	0.004*
Simpson Diversity Index	2.33	0.054

Note: * indicate significant interaction effect at p<0.05.

HLM revealed significantly lower arthropod species richness, abundance, and diversity index values for the soybean field compared to both the boundary and pasture (Table 12), with the exception of Pielou's evenness. Arthropod species richness, abundance, and Margalef Species Richness of the boundary were significantly higher than that of the pasture. However, no significant differences were found for Shannon-Wiener Diversity Index, Pielou's Evenness, and Simpson Diversity index values between the boundary and pasture.

Discussion

Plant species composition

It is generally regarded that spillover of biota between the crop and non-crop habitat occurs frequently (Blitzer et al. 2012; Madeira et al. 2016). In this study, a unique plant species assemblage was identified inside the soybean field and only a few species were shared with the field boundary. It seems that only some plant species that occur in the field boundary disperse into the soybean field to potentially become problematic weeds. In winter wheat and barley agroecosystems in Europe, it was revealed that only 30% of the plant species located inside the field boundary also occurred in the crop, most of which were recorded within 2.5 m of the field boundary (Marshall 1989). Similarly, in this study, it was found that only 20% of the plant species located in the field boundary is shared with the soybean field.

The field boundary also had a different plant species composition compared to adjacent pasture (only 21% overlap in species). In addition, a low number of alien plant species were found in the pasture in contrast to the field boundary. Close proximity to the cropland means the boundary is exposed to disturbances including fertilizer drift, pesticide drift, soil disturbance from turning farm machinery, and the presence of fences and dirt roads (Barbosa et al. 2010; Felsot et al. 2011; Hahn et al. 2015). Similarly, in maize agroecosystems in South Africa, no significant shift in the plant species assemblages was observed in natural habitat beyond 30 m from maize fields (Botha et al. 2015). Therefore, the disturbance effects of crop cultivation on plant diversity and composition seem to be confined to the field boundary, and hence, it explains the observed difference in species assemblages between field boundaries and adjacent pasture.

The ordination indicated that land-use intensity (accounted for by crop fields, roads, fences, and buildings) in soybean agroecosystems was a strong determinant of the variation in plant species assemblages. This was expected as disturbances associated with crop cultivation (Felsot et al. 2011; Plaza et al. 2015) and infrastructure such as buildings and settlements (Lätman et al. 2014) generally result in biodiversity loss. Disturbances act as filters that allow species that are able to tolerate disturbances, to grow and outcompete less tolerant species (Schooler et al. 2010). Furthermore, remnants of natural habitat are separated from each other by land-use, especially by crop species, which form very different assemblages from vegetation types in natural habitat. This will impact the dispersal of species between remnants of natural habitat and ultimately the species diversity and composition of a particular community (Haddad et al. 2015).

At a regional scale, the variance in plant species assemblages that were observed between Winterton and other localities were accounted for by environmental variables. In the ordination, the vegetation of Winterton related strongly to high mean annual rainfall and temperatures, while the communities of other localities dependent on increasing altitude. Winterton forms part of the Northern KwaZulu-Natal Moist Grassland vegetation unit which is characterized by higher mean annual temperatures and precipitation as well as being at lower altitudes than the other localities (Mucina and Rutherford 2006).

Grass species such as *Eragrostis chloromelas* Steud., *Eragrostis curvula* (Schrad.) Nees, and *Themeda triandra* Forssk. were the strongest indicators for the pasture, and their presence also indicates the level of disturbance due to grazing pressure. *Eragrostis curvula* and *E. chloromelas* are known to perform well in disturbed areas of agricultural landscapes (Van Oudtshoorn 2012), and although they were abundant in almost all pasture sample plots, they were also frequently recorded in the disturbed boundary zone. *Themeda triandra* is known to perform poorly in disturbed areas (Snyman et al. 2013) and was almost exclusively found inside the pastures, but was not common.

The field boundary contained six indigenous indicator species and 13 alien species suggesting the presence of disturbance inside the boundary since weedy alien species tend to be abundant in transformed areas. The most significant indicator species were, however, indigenous. These were the pioneer grass species, *Cynodon dactylon* (L.) Pers. and *Eleusine coracana* (L.) Gaertn. (Van Oudtshoorn 2012) that are often the first species to colonize the disturbed boundaries along with crop fields or roadsides.

Commelina benghalensis L. and *Cyperus esculentus* L. were the most important indicator species in soybean fields. *Commelina benghalensis* is an alien weed which is common in both transformed and untransformed ecosystems. Through asexual, vegetative reproduction this species can quickly increase its population density in areas with disturbed soil surfaces (Bromilow 2010). *Cyperus esculentus* is a native grassland species with strong competitive traits allowing it to invade crop fields (Bromilow 2010). *Zea mays* L. was also listed as an indicator species for the soybean field but were likely present as volunteer maize from the previous cultivation season since it is cultivated in rotation with soybean.

Specific trends in species distribution patterns were observed in this study. These trends were similar to the plant species distribution patterns described by Marshall (1989) for agroecosystems in Europe. There were species confined to each treatment zone, for instance, *Malva parviflora* L. and *Oxalis latifolia* Kunth inside the soybean fields, *Bidens pilosa* L., *Tagetes minuta* L. and *Urochloa mossambicensis* (Hack.) Dandy inside field boundaries, and *Andropogon schirensis* Hochst. ex Rich. and *Brachiaria serrata* (Thunb.) Stapf in the adjacent pasture. Several species occurred in both the soybean fields and field boundaries, for example, *Amaranthus hybridus* L., *E. coracana, C. esculentus,* and *C. benghalensis*. There were also species that occurred inside both the boundary and pasture, for instance, *E. curvula, Conyza podocephala* DC. and *C. dactylon*. This agrees with the idea that species can be classified according to habitat preference (in this case cultivated, semi-natural and natural habitat).

Plant diversity patterns

As expected, soybean fields had significantly lower plant diversity and abundance of non-crop plants than the field boundary and pasture. This was expected due to the implementation of weed control measures, either through herbicide application or conventional tillage. These factors have been shown to successfully reduce the abundance and diversity of weeds (Santín-Montanyá et al. 2013). Furthermore, the shading effect of soybean plants may further suppress the growth of weeds once plants become large enough (Datta et al. 2017).

Evenness is important to consider since it is generally stated that ecosystem stability and function increases with increasing diversity and evenness (Maestre et al. 2012; Daly et al. 2015). Here we found the evenness of non-crop plants in soybean fields to be significantly lower than inside boundaries and pastures. We attribute this to agricultural disturbances (herbicide usage, soil disturbance, and invasion by alien species) as they tend to have a destabilizing effect on evenness (Adhikari and Menalled 2018; Gao et al. 2020). Disturbance gives the opportunity for species, that are able to tolerate the disturbance, to dominate. This was also confirmed by our findings since species that dominated within crop fields were often vigorous weeds such as *C. esculentus, C. benghalensis,* and *O. latifolia*.

Agricultural disturbance may also affect plant diversity adjacent to crop fields (Felsot et al. 2011; Schmitz et al. 2014). However, our results showed no significant differences between diversity and evenness index values of the field boundary and pasture. The boundary had maintained species evenness despite the presence of alien plant species in this zone. There was, however, a clear shift from native to alien species composition as described above. Therefore, although agricultural activities in adjacent cropland did not result in a decrease in the overall plant diversity and abundance of field boundaries, in this case at least, it did significantly change the species composition of the plant community inside the boundary.

From this and similar studies, it can be concluded that properly vegetated boundary zones may provide protection of natural habitats against agricultural activities (Botha et al. 2015). Boundary zones may reduce soil erosion and buffer the movement of agrochemicals toward natural habitats (Borin et al. 2010; Alves et al. 2017). Furthermore, several studies reported on the importance of plant diversity for the provision of ecosystem services, as well as the effect that the identity of the species (species composition) may have on ecosystem services (Mace et al. 2012; Faucon et al. 2017). Therefore, the high plant diversity of the field boundary and pasture (compared to cropland), and the unique species composition in each zone, is of further conservation value through its support of arthropod species that perform important ecosystem services beneficial to the entire agroecosystem.

Arthropod species composition

Similar to the plant diversity results, distinct arthropod species assemblages were observed for each zone. This was expected as plant diversity and composition are widely considered as important determinants for arthropod diversity and composition (Haddad et al. 2009; Bennet and Gratton 2013; Botha et al. 2017). Some herbivores exhibit a degree of host plant specificity, which comes to reason that plant species assemblages will directly affect herbivores dependent on these species. Plant species assemblages also determine the vegetation structure, plant chemical complexity, and microclimate which may further affect phytophagous arthropods and higher trophic groups such as parasitoids and predators (Randlkofer et al. 2010; Ratnadass et al. 2011).

Conservation biological pest control is an important ecosystem service in agroecosystems and is largely dependent on predators and parasitoids that colonize the crop from adjacent habitats (Balzan and Moonen 2014; Gagic et al. 2018). Our findings highlight the importance of the boundary and pasture to maintain high diversity and abundance of predators and parasitoids. The field margin provides permanent refuge and alternative food resources and can be considered a reservoir from where biological control agents invade crop fields (Ramsden et al. 2015; Gagic et al. 2018).

Land-use intensity (comprised of crop fields, buildings, roads, and fences) accounted for most of the variation in arthropod species assemblages. This was expected as these activities entail large-scale transformation and fragmentation of natural habitat, with the added potential to further degrade remaining habitat via agrochemical drift, which have adverse effects on arthropod abundance and species richness (Santín-Montanyá et al. 2013; Egan et al. 2014). This suggests that different filters apply to depend on the types of land-use and this requires further research.

At a regional scale, MAP and the geographical position (latitude and longitude) created groupings between localities. It has previously been shown that longitude and latitude explained most of the variation in arthropod species assemblages in the grassland and savanna biomes of South Africa (Botha et al. 2016). These effects were ascribed to possible differences in climatic conditions between geographical positions. For example, South Africa tends to become drier from east to west. The localities of Belfast and Winterton lie on similar longitudinal lines in the eastern parts of the country, and the CCA biplot did show that these two localities were characterized by high MAP (Mucina and Rutherford 2006).

Indicator species analysis also revealed several Noctuidae species, as well as a Nymphalidae and Pentatomidae species, as indicator species for the soybean fields. Several of the important pest species of soybean in South Africa belong to these arthropod families. The most economically important of these species are *Helicoverpa armigera* (Hübner), *Thysanoplusia orichalcea* (F.) (Lepidoptera: Noctuidae), *Vanessa cardui* (L.) (Lepidoptera: Nymphalidae), and *Nezara viridula* (L.) (Hemiptera: Pentatomidae) (Du Plessis 2015). It is important to note that the field margin (boundary and pasture) had multiple entomophagous indicator species while most indicator species for the soybean field were phytophagous. This further emphasizes the conservation value of these zones since these entomophagous species are dependent on the habitat provided by boundary zones and natural habitats in agroecosystems (Botha et al. 2017).

Arthropod diversity patterns

Significantly lower diversity of arthropods was collected from soybean fields than both the field boundaries and pasture. This supports findings by Botha et al. (2015) in maize agroecosystems where lowest arthropod species richness and diversity were recorded inside maize fields. This adverse effect of agriculture on arthropod diversity patterns is ascribed to management and cultivation practices (agrochemical application and tillage) (Pereira et al. 2010). Our results showed that soybean cultivation resulted in low abundance and diversity of non-crop (weedy) plants – a possible contributing factor to the trend observed for arthropod diversity. This is supported by numerous studies which demonstrated that decreasing plant species richness and diversity leads to decreased arthropod diversity and species richness (Haddad et al. 2009; Bennet and Gratton 2013; Botha et al. 2017).

Significantly higher species richness and abundance of arthropods were observed in the boundary compared to the adjacent pasture. No difference in diversity or evenness was found between the two zones. This rejects the hypothesis that the field boundary will have lower arthropod diversity than the pasture due to more intense disturbances associated with this zone. The increased arthropod diversity in the field boundary may be attributed to a possible edge effect. Arthropods are more mobile than plants, and in agroecosystems, a spillover of arthropod species between the crop and non-crop habitat frequently occurs. At any given moment, the boundary may contain species from both the soybean field and the pasture, and including a unique set of species specifically adapted to the environment within the boundary.

This is the first study describing the diversity patterns and species assemblages of non-crop plants and arthropods of soybean fields and field margins, i.e. boundary zones (transition zone between soybean fields and adjacent habitat) and adjacent pasture in South Africa. Similar to maize agroecosystems in South Africa (Botha et al. 2015) arthropod and non-crop plant diversity were severely reduced inside soybean fields. The first hypothesis stating that plant and arthropod diversity of disturbance-prone soybean fields was expected to be lower than the adjacent natural and semi-natural habitats are therefore supported. Plant diversity remained the same for the boundary and adjacent pasture. Higher abundance and species richness of arthropods were recorded in the boundary than the pasture (attributed to an edge effect) while diversity index values remained the same, which rejects the second hypothesis stating that the boundary will have a lower diversity of plants and arthropods due to possible disturbances arising from adjacent crop fields.

Disturbance from crop fields significantly changed the plant and arthropod species assemblages inside the field boundary compared to the surrounding pastures (> 50 m from the crop). This supports the third hypothesis that plant and arthropod species composition of the field boundary will be replaced by unique assemblages of plant and arthropod species that are able to tolerate endo- and exogenous disturbances. Plant and arthropod assemblages in the soybean field were correlated with high land-use intensity, pasture assemblages with low land-use intensity, while boundary assemblages were intermediate. Therefore, this confirms the importance of boundary zones to buffer the effects of crop activities on adjacent natural habitat. Furthermore, contrary to the perception that the boundary is a source for pests and weeds, the boundary zones in this study did not accommodate any soybean arthropod pests or herbicide weeds, but rather beneficial species (such as predators and parasitoids, and fast-growing, stress-tolerant pioneer grasses and forbs). Therefore, maintaining field boundaries is not only important to buffer the effect of crop activities, but functions as a reservoir for beneficial biota in soybean agroecosystems.

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