

Plant and arthropod diversity patterns of maize agro-ecosystems in two grassy biomes of South Africa

M. Botha¹ · S. J. Siebert¹ · J. van den Berg¹ ·
B. G. Maliba^{1,2} · S. M. Ellis³

Received: 3 September 2014/Revised: 27 February 2015/Accepted: 4 March 2015/
Published online: 14 March 2015
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Abstract Intensive, large-scale cultivation has led to a postulated decrease in biodiversity worldwide, which has been ascribed to fragmentation and degradation of natural habitat bordering crop fields. Maize is the most widely planted grain crop in Grassland and Savanna Biomes of South Africa, but the effect that crop production has on surrounding species diversity and composition is unknown. This study intends to address this knowledge gap by comparing diversity patterns and species assemblages between maize fields and margins of six localities in South Africa across two biomes for plants and associated arthropods. A total of 15,019 individuals and 824 native and exotic plant species were recorded and 39 497 individuals and 1 629 morpho-species for arthropods. Although biodiversity loss was apparent in maize fields, plant and arthropod diversity remained the same for rangeland at shorter (30–100 m) and longer (100–400 m) distances from maize fields, suggesting that distance from maize fields had no effect on biodiversity patterns beyond 30 m. Plant species assemblages were best correlated with agricultural disturbance while arthropod communities were mainly correlated with biome. Our results suggest that the crop field margins (30–100 m from field edge) were not species poor ecosystems, but were surprisingly rich in plant and arthropod diversity. Field margins may therefore be of

Communicated by Anurag chaurasia.

Electronic supplementary material The online version of this article (doi:[10.1007/s10531-015-0901-0](https://doi.org/10.1007/s10531-015-0901-0)) contains supplementary material, which is available to authorized users.

✉ M. Botha
moniquebotha210@gmail.com

¹ Unit of Environmental Sciences and Management, North-West University, Private Bag X6001, Potchefstroom 2520, South Africa

² Eskom, Research, Test and Development, Private Bag X40175, Cleveland 2022, South Africa

³ Statistical Consultation Services, Unit for Business Mathematics and Informatics, North-West University, Private Bag X6001, Potchefstroom 2520, South Africa

conservation value in the agricultural landscape with a diversity of species supporting important ecosystem services.

Keywords Agriculture · Diversity indices · Ecosystem services · Grassland · Field margin · Savanna

Introduction

Biodiversity is increasingly coming under threat worldwide due to anthropogenic activities. As the human population expands, areas for habitation and food production must inevitably increase to meet the growing demand. Vast areas of land have been transformed for production of food crops, for instance, 86 % of land in South Africa is zoned for agriculture, of which 13 % is used for cultivation of crops (DEAT 2005). *Zea mays* L. is the most important grain crop in the country and by the end of 2011, the area of farmland allocated to maize production in South Africa was 2.86 million hectares (Hannon 2012).

This large scale transformation of natural vegetation poses a serious and growing threat to biodiversity (Darkoh 2003; Wessels et al. 2003). Commercial cropping systems are unstable ecosystems and simply cannot support levels of non-crop diversity equal to natural ecosystems (Tivy 1990). Hence, the transformation of natural habitat into crop fields inevitably leads to species loss. This effect may however extend well beyond the boundary of the crop itself. Several studies have shown that the presence of crop fields often cause significant alterations in plant and invertebrate community structure in adjacent natural habitat (Boutin and Jobin 1998; Carrière et al. 2009; McKone et al. 2001; Oleszczuk et al. 2010; Piessens et al. 2006) and may result in an overall reduction in diversity and richness in field margins. This effect could extend to considerable distances from the fields when aspects such as agrochemical and genetically modified (GM) plant material drift are taken into account. For instance, studies by Beckie and Hall (2008), Devos et al. (2009), Hofmann et al. (2010), Messeguer et al. (2006), Rosi-Marshall et al. (2007) and Viljoen and Chetty (2011) seem to indicate that the critical zone for maize pollen deposition is in the first 150 m from maize fields; although Sanvido et al. (2008) found 400 m to be the furthest point at which cross fertilisation between GM and non-GM maize occurred.

It is generally agreed that biodiversity plays a major role in the functioning of ecosystems and is generally considered to be an important aspect in both natural and agricultural ecosystems (Altieri 1999; Bond 1989; Duelli et al. 1999; Wessels et al. 2003). Understanding exactly what effect the anthropocene has on the complexity and interactions of ecosystems and its responses to disturbance is often measured in terms of biodiversity loss (Siebert 2011). Higher biodiversity is, for instance, required to escalate suppression of insect pest numbers within agro-ecosystems (Gurr et al. 2012; Ratnadass et al. 2012). It has therefore become increasingly important to understand the effect of our activities on biodiversity to regulate the management and conservation of natural systems for our benefit.

Research concerning fauna and flora of agro-ecosystems often involve only one or two key species (often pests or weeds) and studies that include complete diversity are scarce (Meissle et al. 2012). Furthermore, there is a need for surveys of arthropod diversity in field

margins adjacent to crop fields and to link this data to non-crop plant communities (Meissle et al. 2012). In South Africa, baseline biodiversity data from agro-ecosystems in either crop fields or surrounding margins are lacking. Cropping systems are such a common feature in South Africa that it has become necessary to understand what effects these activities may have on the biodiversity of the adjacent landscape. As primary producers, plants form the basis of most terrestrial food chains and it is known that changes in plant diversity or species composition may in turn affect the nature of consumer populations (Caballero-López et al. 2010, Schaffers et al. 2008, Schellhorn and Sork 1997, Siemann et al. 1998). Furthermore, arthropods increase our knowledge of total biodiversity (or species richness) and in addition serve as useful bio-indicators to disturbance since they are present in almost all environments. They react to environmental changes more rapidly than vertebrates and can provide early detection of ecological changes (Rodríguez et al. 1998, Kremen et al. 1993). They also provide valuable ecosystem services in agro-ecosystems such as biological pest control (Moolman et al. 2013) and pollination (Aizen et al. 2008, Klein et al. 2007, Stary and Pike 1999), and are an important food source for vertebrate taxa (Ponce et al. 2014). As such, plants and arthropods are useful representatives of total biodiversity within ecosystems. Therefore, the aims of this study were to compare plant and arthropod diversity patterns and species assemblages of maize agro-ecosystems along a maize field–field margin gradient at the local scale and between two grassy biomes (grassland and savanna) at the regional scale.

At farm level, crop fields are intensively transformed systems (Tivy 1990) and the disturbances associated with this transformation may affect the diversity and species composition of biota in adjacent rangeland (Bundschuh et al. 2012, De Snoo and De Wit 1998, De Snoo and Van der Poll 1999, Marshall and Moonen 2002). Therefore, we hypothesized that plant and arthropod diversity of field margins would be negatively affected by maize fields and would result in a reduction of species richness and diversity. To compensate for species loss and to maintain ecosystem functioning in disturbed areas, disturbance intolerant species would then be replaced by disturbance tolerant species (Yachi and Loreau 1999; Siebert 2011). Our second hypothesis proposed that field margin diversity would therefore be replaced by a unique set of species (assemblages) that are presumably better adapted to tolerate disturbance. At a regional level, climatic differences and management regimes could also have an effect on the diversity and species composition of biota in agro-ecosystems. Savanna is multi-layered with more niches than the grassland biome (Curry 1994; Schadek et al. 2009) and our third hypothesis therefore stated that the multi-layered natural vegetation of the savanna biome would contain higher plant and arthropod diversity than the grassland biome (refer to biome distribution map, Fig. 1). Anthropogenic activities have a tendency to degrade beta diversity, resulting in biotic homogenization at the regional scale (McKinney and Lockwood 1999). These activities include agriculture, and therefore our fourth hypothesis proposed that maize fields would have lower beta diversity (less species turnover between biomes) compared to natural environments.

It is important to note that the disturbances of agricultural activities should have different effects on different plant and arthropod functional groups (Liira et al. 2008, Oliver and Beattie 1996). The individual responses of separate groups are however outside the scope of this study, which focused on trends of total plant and arthropod diversity.

Materials and methods

Study areas

Study areas were selected from the six major maize producing provinces of South Africa namely the Eastern Cape, Free State, KwaZulu-Natal, Limpopo, Mpumalanga and North-West (Fig. 1). This translates into three representative study areas being chosen for each of the two biomes (Fig. 1). Each locality has its own set of environmental variables and management regimes including biome, vegetation unit, altitude, farming type, presence or absence of irrigation and width between rows of maize (Table 1).

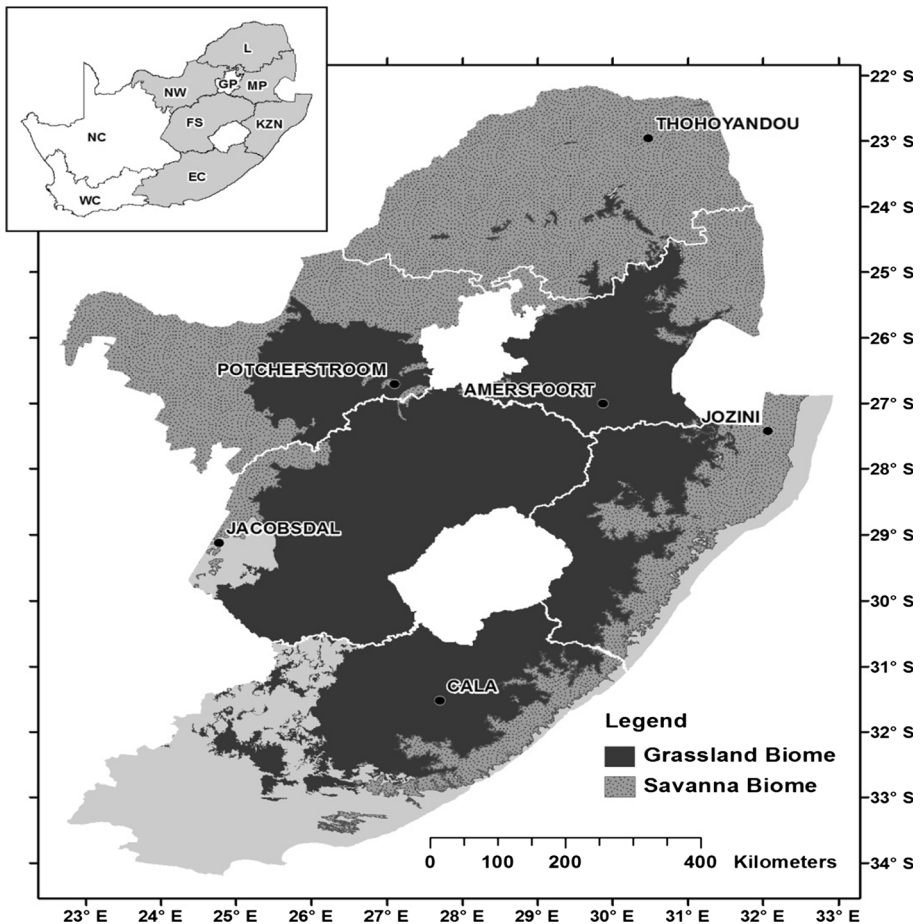


Fig. 1 Distribution of the grassland and savanna biomes of South Africa in relation to the nearest town of each survey locality and across the six major maize producing provinces of South Africa: *L* Limpopo, *MP* Mpumalanga, *KZN* KwaZulu-Natal, *EC* Eastern Cape, *FS* Free State, *NW* North-West

Table 1 Summary of general information for localities

Locality	Biome	Vegetation unit	Altitude (m a.s.l.)	Farming type	Irrigation	Row width (cm)
Amersfoort	Grassland	Amersfoort Highveld Clay Grassland	1689–1747	Commercial	Dry	90–100
Cala	Grassland	Tsomo Grassland	836–916	Commercial	Dry	100–150
Jacobsdal	Savanna	Kimberley Thornveld	1144–1172	Commercial	Irrigation	75–100
Jozini	Savanna	Western Maputaland Clay Bushveld	69–112	Subsistence	Irrigation	80–100
Potchefstroom	Grassland	Rand Highveld Grassland	1407–1490	Commercial	Dry	150–200
Thohoyandou	Savanna	Makuleke Sandy Bushveld	613–680	Subsistence	Irrigation	90–100

Biome and vegetation unit according to Mucina and Rutherford (2006)

Experimental layout

Surveys were conducted from November 2009 to March 2012 during the regional flowering periods of maize. At each of the six localities, four sites (each comprising a maize field bordering on rangeland), approximately 5 km apart, were selected. At each locality the four sites were positioned to capture the variability in the topography, namely two sites on hill slopes and two in the valleys. The gradient along hills or valleys was respectively sampled with one site running upslope and the other downslope in relation to the maize field. However, the feasibility of this design depended on access to land and position of other environmental features in the landscape.

Twenty-four points were sampled at each of the six localities, consisting of four sites per locality and six sampling points per site. Sampling points were placed along a 500 m long maize field–field margin gradient. Points were spaced per site to ensure that two were located in each of three distance classes: In maize fields (between 100 and 30 m from crop edge) and in adjacent rangeland at short (30–100 m) and long (100–400 m) distances from maize fields (Fig. 2). Sample points were placed parallel along the gradient, never less than 50 m or more than 100 m apart.

Sample points inside maize fields were positioned within the actively cultivated area or main crop up to 100 m into the field, measured from and excluding the crop edge (the ‘headland’ which comprises the 10–20 m distance directly outside the crop which is often used as turning space for machinery). Rangeland points at short distances (hereafter RSD) from maize fields were positioned up to 100 m away from, and excluding the margin strip (10–20 m of semi-natural habitat outside the crop edge with a high level of anthropological disturbance) (Marshall and Moonen 2002). Care was taken to always sample maize fields with large stretches of adjacent rangeland and never strips between two fields, or between fields and features such as roads or buildings. Rangeland points at longer distances from maize fields (RLD) were positioned furthest away (between 100 and 400 m). At each sample point arthropods were sampled first in plots of 25 m² (5 × 5 m). Transects for the vegetation sampling were then placed over these plots to sample an area of 400 m².

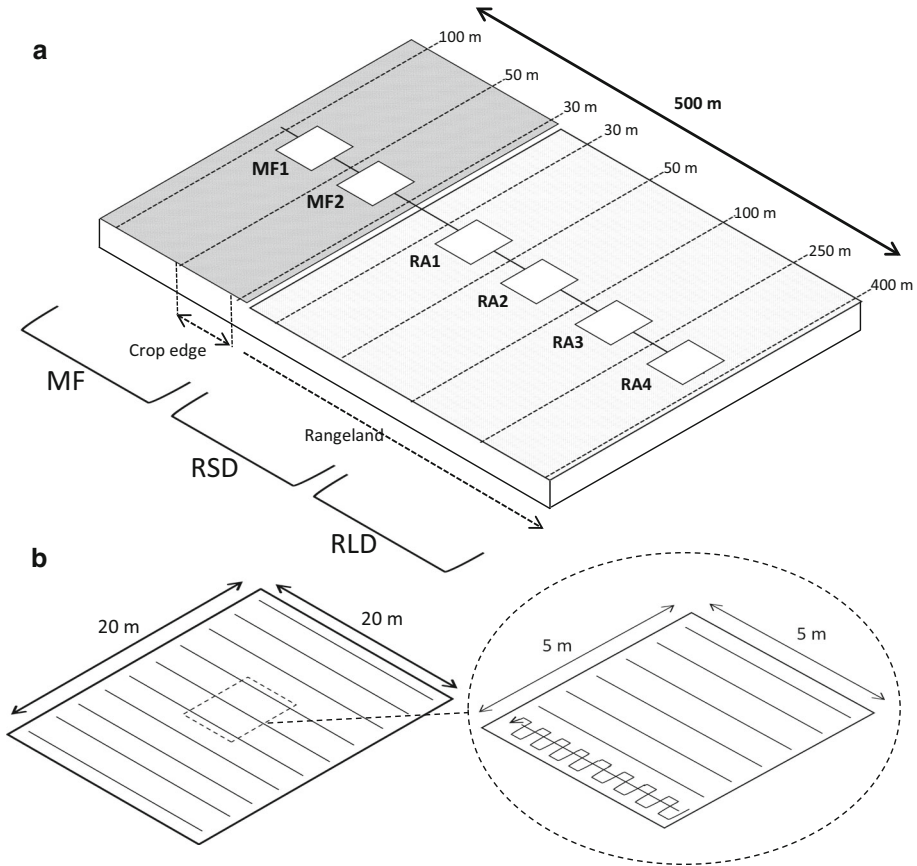


Fig. 2 **a** Sampling points along a maize field–field margin gradient in a maize agro-ecosystem; zones: MF, maize field; RSD, rangeland short distance; RLD, rangeland long distance. **b** Sample points consisted of ten parallel, fixed width (2 m) line transects for plant surveys (*left*). Arthropod surveys (*insert right*) were conducted in the centre of each plant survey area and D-vac suction sampling was conducted in a zigzag pattern as indicated

Arthropod sampling

The target group for this survey included plant-dwelling arthropods that occur in the maize agro-ecosystem during the reproductive stages (flowering) of maize. Therefore, surveys were scheduled to coincide with the regional flowering times of maize at each of the study localities. Studies have shown that these plant growth stages capture different trophic levels and that it is an ideal time to sample a comprehensive arthropod community in maize (Eckert et al. 2006).

An adapted D-vac method was used for arthropod collection (Dietrick et al. 1960). This is a relatively fast method for sampling large areas of vegetation, although its effectiveness may be altered by weather conditions and vegetation characteristics. It is really only effective in dry, upright vegetation that is not more than 15 cm high (Southwood and Henderson 2000). Suction in dense vegetation may selectively extract certain species and under-sample others (Elliott et al. 2006). Therefore, it may be an effective method in

grassy habitats, if not in dense woodlands. However, unlike passive methods such as pitfall traps the D-vac method is not as dependent on insect activity, is less prone to error (Thomas and Marshall 1999) and may represent one of the best techniques for sampling a wide range of arthropod taxa in vegetation.

Because the performance of the D-vac method is dependent on weather conditions, it was attempted to sample arthropods under relatively similar weather conditions across localities and no sampling was conducted in wet conditions or at high wind speeds. Seven swaths per plot were made, following a zigzag pattern with the D-vac nozzle in each swath. No samples were taken of soil arthropods and this study is therefore based on above-ground plant-dwelling arthropods. Soil-dwelling arthropods that occurred below plant debris or that were present at the lower parts of plants during the survey were also collected but the aim was not to use the D-vac to collect on the soil surface itself.

The collected preserved arthropod taxa were assessed following a rapid and cost effective method involving classification to morpho-species level. It has been shown that this method can provide estimates of richness and turnover similar to methods that make use of species classified by taxonomists (Oliver and Beattie 1996). Care was taken to insure that a morpho-species was regarded as the same ‘species’ for the entire sample (across all transects and localities) by compiling a photographic guide to which new individuals were compared. Classifications follow Picker et al. (2004) and Scholtz and Holm (1985). The number and abundance of each morpho-species was further determined for each plot.

Vegetation sampling

At each sampling point a fixed width (2 m) line transect approach was followed (Hill et al. 2005) and adapted to include ten parallel transects of 20 m each, along which plant species were recorded. This ensured that the vegetation sampling would overlap with the same area as the arthropod sampling. A continuous single 100 m transect would have extended 47.5 m in two directions away from the arthropod sample point, but our modification reduced this distance to 7.5 m in all directions to provide a more accurate representative sample of the vegetation associated with the arthropods. At 1 m intervals, one plant species was recorded for every major growth form, that is, grass, herb, shrub and tree. Therefore, a maximum of four species were recorded at each 1 m interval if all growth forms were represented. The number of individuals per species across the ten transects was summed to determine the species abundances for the sample point.¹ Plants were identified up to species level and species names follow Germishuizen et al. (2006). Only ten specimens remained unidentified and were treated as morpho-species.

Biodiversity quantification

The term biodiversity is often synonymous with species richness, the number of species in a given sample (S). However, the multi-faceted nature of biodiversity may be more sufficiently described by diversity indices (Begon et al. 2008). In this study, two types of diversity indices were used, namely those that emphasises species richness and those that condense both species richness and evenness (how equally abundant species are) into a single value, also referred to as heterogeneity indices (Magurran 1988).

Margalef’s species richness index (d) was used as an additional species richness measure as it compensates for the sampling effect by dividing richness (S) by the total number

¹ A complete list of all recorded plant and arthropod taxa is available in online resources 1 and 2.

of individuals in a sample (N). It may therefore be a more meaningful measure of species richness than simple species counts. It is unfortunately not completely uninfluenced by sampling effort (Magurran 2004).

The Shannon–Wiener diversity index, Simpson’s diversity index and Pielou’s evenness were used as heterogeneity measures. The Shannon–Wiener diversity index (H') remains one of the most popular diversity indices used in the literature (Samways 1984) and is therefore valuable for comparison between studies. As a heterogeneity measure, the index condenses species richness and evenness into a single figure. However, this can make interpretation difficult since an increase in the index value may be attributed to greater species richness, evenness or both. The Shannon–Wiener index however tends to weigh towards species richness and is also dependent on sample size, although not as severely as species richness (Magurran 1988).

Simpson’s diversity index (\hat{D}) is expressed as $1-D$ (the complement of Simpson’s index). It is considered to be one of the most robust and meaningful diversity indices and it is also known as a dominance or evenness measure, as it is weighted towards abundances of the commonest species rather than species richness (Magurran 2004). Therefore \hat{D} will increase with increasing evenness in a given sample. Despite emphasising evenness over species richness, it is not considered to be an evenness measure per se (Magurran 2004).

As such, Pielou’s evenness (J') was used to determine evenness or dominance patterns in the dataset. Also known as the Shannon evenness measure, it is derived from the Shannon–Wiener diversity index and uses the ratio of observed diversity to maximum diversity to measure evenness (Pielou 1975). Pielou’s evenness values range from 0 to 1.0, with 1.0 representing complete evenness (Magurran 2004).

The abovementioned indices display different aspects of species diversity and were therefore used in combination to provide a more complete picture of species richness and diversity. Index values were calculated using PRIMER 6 software (Clarke and Gorley, 2006).

Statistical analyses

Hierarchical linear models (HLM) were performed on the dataset in SPSS software package (Hancock and Mueller 2010) to test for overall significant differences in index values between biomes and across maize field–field margin gradients. Transects were specified as subject (ID) to account for the nestedness of transects within locality. The covariance structure was specified as unstructured. Each transect along the maize field–field margin gradient was considered an independent variable for statistical analyses. Effect sizes (Cohen’s d) were used to express practical significance between sampling points where residual variance as well as transect variance were taken into account in the calculation of the effect size (Ellis and Steyn 2003). The effect sizes were interpreted as follows: small effect: $d = 0.2$, (b) medium effect: $d = 0.5$ and (c) large effect: $d = 0.8$ (Cohen 1988).

Canonical correspondence analysis (CCA) (Ter Braak 1986) was applied to the data using PAST software (Hammer et al. 2001) to depict how different points compared in terms of arthropod and plant species composition and to assess the relative importance of the environmental variables and management regimes in determining plant and arthropod species assemblages of the various sampling points. Five factors were considered for a biplot with species data. These included distance from maize field (m), disturbance (negatively related to distance), biome (grassland or savanna), altitude (m a.s.l.) and farming practice (commercial or subsistence).

To test whether overall significant differences exist between points in different distance classes and biomes in terms of species composition, the Adonis programme in package *vegan* in R (Oksanen 2011) was used, which is appropriate for taking into account nestedness of the data within transects. In addition, Analysis of Similarity (ANOSIM), a non-parametric test for significant differences, was performed with PAST software (Hammer et al. 2001) to illustrate significant differences in a pairwise format.

Results

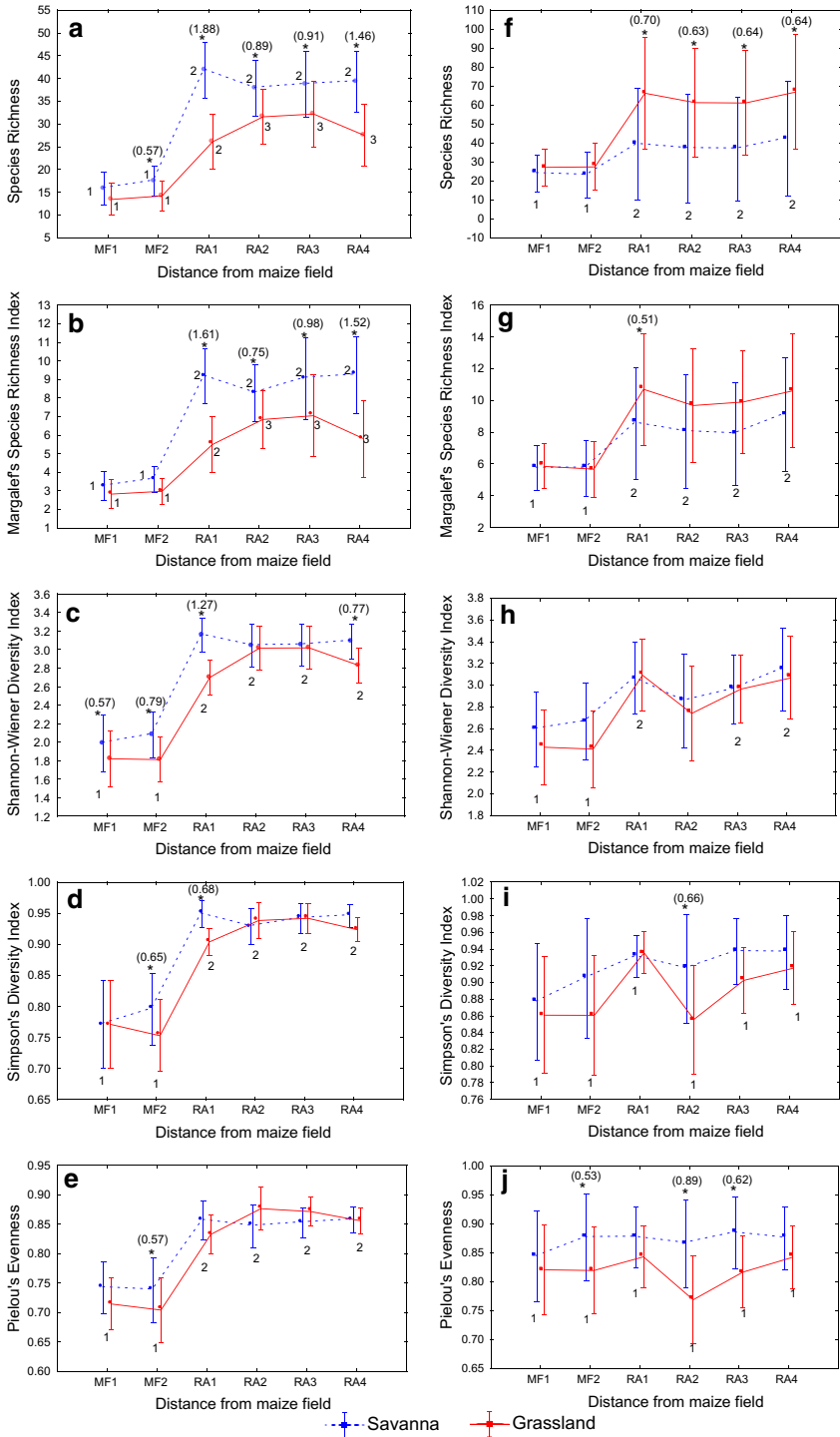
Plant diversity patterns

The plant study recorded 15,019 individuals representing 824 native and exotic species (including *Z. mays*) in 95 families, with 148 species recorded from maize fields, 584 from RSD points and 570 from RLD points. Approximately 10 % (86 species) of species were alien weeds. Most were found inside the maize fields (64 species), while the RSD and RLD points collectively contained 55 alien species. The largest proportion of alien species relative to the total number of species in each distance class was found in the maize fields (42 %) compared to 4 and 5 % of alien plant species recorded in the floras of the RSD and RLD points respectively.

Comparisons of species richness between points along the maize field–field margin gradients of the grassland and savanna biomes revealed that the number of plant species was significantly lower in maize fields compared to rangeland (Fig. 3a; also refer to Appendix Tables 4 and 5 for statistical values). However, there were no significant differences in the number of plant species between RSD and RLD points. A significant interaction effect was found between biome and distance, indicating that the grassland and savanna biome reacted differently to distance (Fig. 3a). This difference occurred mainly in the rangeland, where the points at 30–50 m (RA1) from maize fields in grassland had significantly lower species richness values than points at 50–250 m (RA2 and RA3) (refer to Appendix Table 6). This was not the case for savanna. Also, plant species richness in the savanna levels off while grassland plant species richness decreases (Fig. 3a, b) with increasing distance away from maize fields. The savanna biome had higher plant species richness than the grassland biome, except inside the main crop (MF1), approximately 100 m from the field margin (Appendix Table 7). The effect was most significant for rangeland sampling points.

Margalef's species richness index revealed similar trends across the maize field–field margin gradient, with significant differences in plant species richness between maize fields and rangeland, but not between RSD and RLD areas (Fig. 3b). Biomes also reacted differently to distance in the RLD area, as indicated by the significant interaction. The index also indicated significantly higher species richness for savanna compared to grassland, although this was only true for the rangeland points (Fig. 3b).

All three heterogeneity indices, that is, the Shannon–Wiener diversity index, Simpson's diversity index and Pielou's evenness (Fig. 3c, d, e) reacted in a similar way to the species richness measures (Fig. 3a, b), with the only significant variation in plant diversity between maize fields and rangeland. As the Simpson's diversity index (Fig. 3d) is weighted towards plant evenness, this indicates that plant species evenness is not statistically different in RSD and RLD areas. This is also confirmed by the results for Pielou's evenness (Fig. 3e) and was consistent for both biomes. Significant differences between the savanna and



◀ **Fig. 3** Diversity measures for plants (a–e) and arthropods (f–j) along maize field–field margin gradients in two biomes of South Africa. Significant differences ($p < 0.05$) between distances along the gradient are indicated by different numbers (savanna and grassland react similarly, except for **a** and **b**, where the biomes showed a different effect at RA1). *Significant variation between biomes at similar distances ($p < 0.05$) and values in parenthesis indicate size effects. Vertical bars denote 0.95 confidence intervals. Zones (corresponds to Fig. 2): MF1 and MF2, maize field; RA1 and RA2, rangeland (30–100 m) RA3 and RA4, rangeland (100–400 m)

grassland biomes were found for the Shannon index, and to a lesser extent for Simpson's index and Pielou's evenness. Significant variation was most evident in the first 50 m of the maize field and the first 50 m of the RSD area, with savanna always displaying the higher values (due to the sampling approach relying on growth forms and not total individuals) and seemingly peaking at 30–50 m, and the grassland diversity peaking at 80–100 m from the maize field.

Plant species composition patterns

In the biplot of Canonical Correspondence Analysis (CCA) for sample points the distance from maize field and disturbance level were closely correlated with axis 1, while biome, altitude and farming practice were more strongly correlated with axis 2 (Fig. 4a; Table 2). Axis 1 and 2 explained 31.93 and 29.38 % of the total variation respectively. The most important factors correlated with plant species assemblages were disturbance (which is negatively correlated with distance from fields), separating the maize fields from the rangelands at the local level, and at the regional level, climate, separating the biomes. Altitude and farming practice had weaker correlations with plant species composition.

Overall, the biplot revealed three distinctive groupings of the plant sampling points. The first group represented maize fields that are characterised by high levels of disturbance. The second group represented savanna that are characterised by low levels of disturbance, lower altitudes and subsistence type farming practices. The third group represented grassland, characterised by low levels of disturbance, higher altitudes and more commercialised maize production systems. Therefore, maize field points represented distinctive clusters relative to rangeland points, while RSD and RLD points clustered together according to biome. This suggests that RSD and RLD points of each biome were not different in terms of species assemblages. This was in accordance with the Adonis results (Appendix Table 8), which displayed highly significant differences between biome and distance class groups at $p = 0.001$.

The pairwise comparisons of ANOSIM analyses (Table 3) indicated differences in species composition between maize fields, RSD and RLD areas, and also between biomes at $p < 0.005$. However, within biomes, the RSD and RLD areas did not differ significantly. These results therefore confirmed the groupings found in the CCA analysis. ANOSIM analyses also showed differences in plant species composition between maize fields of grassland and savanna, indicating that maize fields have relatively unique weed communities specific to biome (note that the analyses were based on a dataset excluding maize plant counts). Furthermore, plant assemblages within rangelands of the grassland biome had a much tighter clustering compared to the savanna sampling points. This is confirmed by the lower p value for the comparison between grassland RSD and RLD areas (Table 3). It must be added that, although all three of the above mentioned analyses displayed similar trends, the results for species composition must be handled with caution due to the abundance of zero values in the data sets and that the ANOSIM analysis could not take into account the nestedness of data within transects.

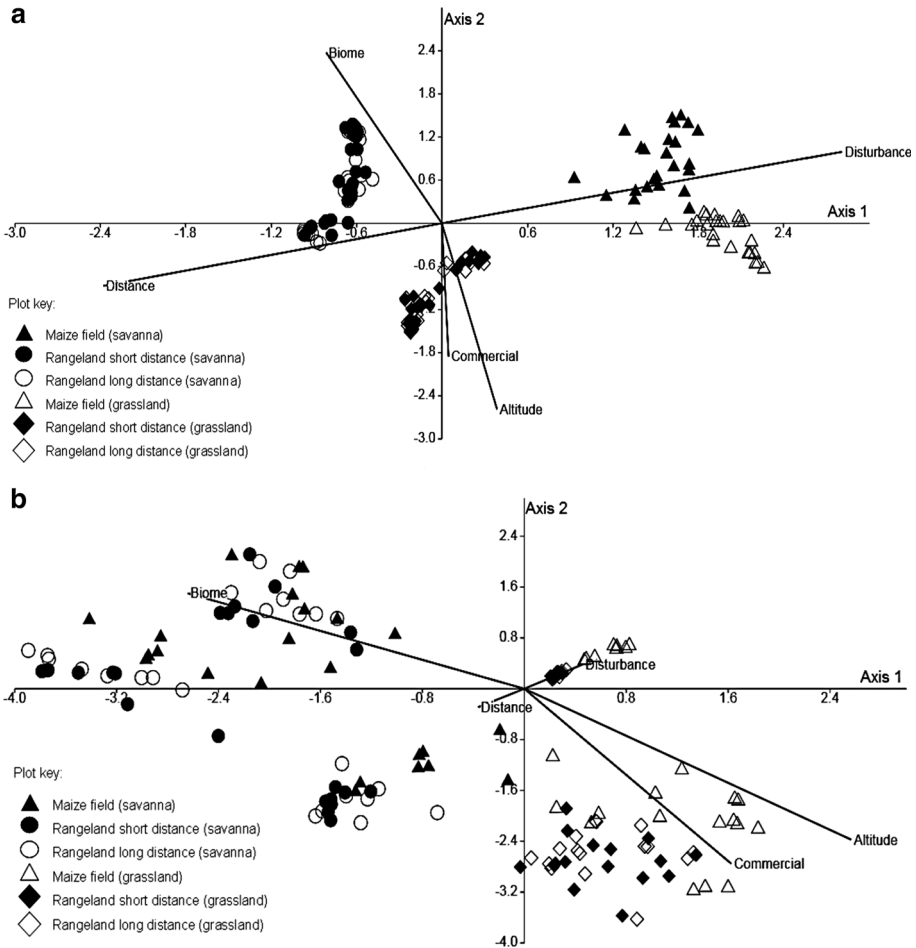


Fig. 4 Canonical correspondence ordination of all sampled localities, showing correlations for environmental variables of **a** plant and **b** arthropod sampling points. Environmental variables are represented by lines and sampling points by symbols. Each symbol represents the weighted average of one plot. Environmental factors were: Distance (distance from maize field); Disturbance (increasing with decreasing distance from maize field); Biome (grassland/savanna); Altitude (m a.s.l.) and Farming practice (commercial/subsistence)

Arthropod diversity patterns

A total of 117 arthropod families, 1629 morpho-species and 39,497 individuals were recorded. This amounted to 576 morpho-species for maize fields, 1031 for RSD points and 1023 for RLD points. The arthropods collected during the study belonged to 23 orders with the most dominant ones being the Hemiptera (true bugs) followed by the Hymenoptera (bees, wasps and ants), Diptera (flies), Coleoptera (beetles), Araneae (spiders) and Orthoptera (crickets, grasshoppers, and locusts).

Arthropod species richness measures both revealed significant variation in arthropod species numbers between maize fields and rangelands, but not between RSD and RLD areas within the rangelands (Fig. 3f, g; also refer to Appendix Tables 4 and 9 for statistical

Table 2 Correlations of ordination axes with environmental factors as well as eigenvalues and percentage variance explained for canonical correspondence analysis of plants and arthropod sample points at all localities

Survey	Factor	Axis 1	Axis 2
Plants	Distance	-0.793	-0.290
	Disturbance	0.936	0.331
	Biome	-0.271	0.792
	Altitude	0.130	-0.863
	Commercial	0.016	-0.620
	Eigenvalue	0.830	0.764
	% variance explained	31.93	29.38
Arthropods	Distance	-0.121	-0.097
	Disturbance	0.152	0.127
	Biome	-0.880	0.501
	Altitude	0.855	-0.791
	Commercial	0.541	-0.917
	Eigenvalue	0.645	0.574
	% variance explained	33.22	29.58

Table 3 ANOSIM analysis indicating significance of separation between plant and arthropod groups based on species composition

Survey	Maize (S)	Maize (G)	RSD (S)	RSD (G)	RLD (S)
Plants					
Maize (G)	0.0001*	–	–	–	–
RSD (S)	0.0001*	0.0001*	–	–	–
RSD (G)	0.0001*	0.0001*	0.0001*	–	–
RLD (S)	0.0001*	0.0001*	0.8084	0.0001*	–
RLD (G)	0.0001*	0.0001*	0.0001*	0.6583	0.0001*
Arthropods					
Maize (G)	0.0001*	–	–	–	–
RSD (S)	0.0005*	0.0001*	–	–	–
RSD (G)	0.0001*	0.0001*	0.0001*	–	–
RLD (S)	0.0013*	0.0001*	0.8324	0.0001*	–
RLD (G)	0.0001*	0.0001*	0.0001*	0.8040	0.0001*

Maize (G) Maize field, Grassland biome; *Maize (S)* Maize field, Savanna biome; *RSD (G)* Rangeland Short Distance (30–100 m), Grassland biome; *RSD (S)* Rangeland Short Distance, Savanna biome; *RLD (G)* Rangeland Long Distance (100–400 m), Grassland biome; *RLD (S)* Rangeland Long Distance, Savanna biome

* Significant p values at $p < 0.05$

values). This is similar to what was found for plant species richness measures. The non-significant interaction for both species counts and Margalef’s species richness index (Appendix Table 6) indicates that both the grassland and savanna biomes reacted similarly to distance regarding species numbers. However, grassland was found to have significantly higher arthropod species richness than the savanna (Fig. 3f, Appendix Table 7), although only in rangelands. This is in contrast to the results for plant species richness, where the savanna biome had significantly higher richness than the grassland biome.

The Shannon–Wiener diversity index revealed similar results to the species richness measures (Fig. 3h) along the maize field–field margin gradient. Diversity seems to peak in

the first 30–50 m from the maize field in the RSD area. In contrast to richness however, no significant differences were found between the grassland and savanna biomes in terms of the Shannon index. These results were consistent across the two biomes as indicated by the non-significant interaction (Appendix Table 6).

For Simpson's diversity index (Fig. 3i), no significant differences were found at any of the distances along the maize field–field margin gradient and were consistent for both biomes, as indicated by the non-significant interaction (Appendix Table 6). This was also found for Pielou's evenness (Fig. 3j), and indicates that arthropod abundances within communities did not differ across the whole gradient. This indicates that significant increases in arthropod diversity index values in RSD areas were likely due to the increase in species richness and not abundance. Since the values of Pielou's evenness mostly ranged between 0.8 and 0.9 for arthropods (Fig. 3j), the abundance of arthropod species are evenly distributed with no species dominance in both maize fields and rangelands.

Arthropod species composition patterns

A CCA biplot (Fig. 4b) indicated that distance and disturbance were less correlated with arthropod distribution than those representing biome, altitude and farming practice. Axis 1 and 2 explained 33.22 % and 29.58 % of the total variation in species composition respectively. Arthropod species assemblages were more strongly correlated with climatic related factors such as biome and altitude. For arthropod sampling points, the biplot revealed two relatively distinctive groups. The first group represented savanna maize fields and rangelands, characterised by lower altitudes and subsistence type farming practices. The second group represented maize fields and rangelands located in the grassland biome, characterised by higher altitudes and commercialised maize farming systems.

Adonis analysis (Appendix Table 8) revealed significant distinctions between biome and distance class groups in terms of species composition at $p = 0.001$. Although less well defined than for plants, ANOSIM analysis revealed distinctive groupings for arthropod species composition of maize fields and rangelands ($p = 0.001$, Table 3). However, the RSD and RLD points within rangelands did not represent separate clusters in any of the biomes, indicating that arthropod species composition was not different between these two areas. Furthermore, rangeland points of grassland and savanna were found to be significantly different in terms of species composition and represented separate clusters (Fig. 4b; Table 3). From the CCA ordination it also appears as though the overlap in arthropod species between the savanna maize sampling points with its margins was more prominent than within the grassland biome, although this was not confirmed by the ANOSIM analysis. Again the results for species composition must be handled with caution due to the abundance of zero values in the data sets and it must also be taken into account that the ANOSIM analysis did not consider the nestedness of data within transects.

Discussion

Plant diversity patterns

Plant diversity is inevitably lost with increased land management or land use intensity (Hamre et al. 2010; Marshall and Arnold 1995; Niedrist et al. 2009). A crop field environment is unfavourable to many plant species due to application of herbicides and

disturbance of the soil (Altieri 1999) as well as growth and shading effects of crop plants, which may result in weed growth suppression (Khan et al. 2006). This leads to the loss of plant species. Unfortunately, agricultural activities have the potential to influence plant communities at considerable distances outside the area of active cultivation through aspects such as agrochemical drift (De Snoo and Van der Poll 1999). Disturbances associated with crop fields may ultimately lead to the loss of plant species richness and diversity as well as species evenness in these agro-ecosystems (Kleijn and Snoeijs 1997, Marrs 1993, De Cauwer et al. 2006). While marked differences were observed for plant species richness, diversity and evenness between maize fields and rangeland, this was not the case for RSD and RLD areas within rangelands. In both these areas the plant species richness and diversity were found to be similar to pristine grasslands in South Africa (Van Oudtshoorn et al. 2011). In addition, all the plant species were also well represented across the whole rangeland habitat (high evenness), contrary to maize field plant communities, which are probably dominated by a few hardy plant species able to withstand the high levels of disturbance (Curry 1994). Plant evenness in crop fields may have been affected by several factors such as fertilization and the application of herbicides. It has been shown that the application of herbicides has a destabilizing effect on plant communities (Kleijn and Snoeijs 1997). On the other hand, it is commonly stated that the species evenness of a community increases with increasing diversity and stability and decreasing anthropogenic disturbance (Chapin et al. 2000; Gurr et al. 2012; Matson et al. 1997), and that plant communities that display higher species evenness are generally healthier (Hillebrand et al. 2008).

Our results indicate that the only detectable disturbance resided within the maize fields and, contrary to our original hypothesis, agricultural practices do not have an overall negative impact on plant diversity of crop field margins, at least not at the distance of 30–150 m. This is further supported by our findings that there was no displacement of indigenous with alien plant species in the RSD area, which would have been an additional indication of active disturbance. It contradicts the notion that crop field margins are disturbed sites with altered plant communities due to their close proximity to agricultural activities (Marshall and Moonen 2002). Negative effects, if present, may be extremely localized, impacting only the very edge (≤ 10 m) between the rangeland and the maize field. It was proposed by Fridley et al. (2009) that agricultural influences on landscape-scale vegetation patterns are in close proximity to agricultural activities (≤ 50 m) as species composition and richness did not differ significantly beyond this point. Similar studies of vegetation responses to activities associated with crop fields indicated that changes in vegetation of field margins occurred within no more than 9 m from crop fields (Boutin and Jobin 1998; Gove et al. 2007). It must also be noted that these results are scale dependent and therefore, studies conducted under different spatial scales may not yield similar results (Ma 2008).

The mostly consistent trends along the maize field–field margin gradient of both the grassland and savanna biomes indicates that the distinctive plant communities associated with the two different biomes respond similarly to the presence of maize fields. However, it was found that grassland followed slightly different trends than the savanna in the first 30–250 m of the gradient in terms of plant species richness. In this case, grassland species richness increased more gradually along the gradient compared to savanna. This result cannot be explained at this point. It is possible that the two biomes reacted differently to disturbances unrelated to the maize fields. It is known for instance that different vegetation types react differently to livestock grazing (Tainton 1999), which was a common feature in

the RSD area. Another probability is that fire wood was extensively harvested at savanna sites, which opens up niches to be colonised and increases diversity.

Overall, plant species richness, diversity and evenness were almost always higher in savanna compared to grassland. However, the significance of these values was not conclusive for plant diversity and evenness. It seems that the only true differences between the grassland and savanna biomes were in terms of plant species richness. The savanna always had significantly higher plant species richness than the grassland biome in the rangelands, although not in the maize fields. This is in accord with our hypothesis that savanna should be more speciose than the grassland biome due to its multi-layered nature (Curry 1994, Schadek et al. 2009).

Plant species composition patterns

In the CCA ordination results (Fig. 4a) the disturbance factor (along with distance) is represented by the longest vector and is best correlated with axis 1 (the axis explaining most of the variation in species assemblages) than either biome, altitude or farming practice (Table 2). This indicates that the degree of disturbance in a maize field-rangeland environment was a very strong correlate of plant species assemblages. This was expected given that plants are organisms with high habitat quality requirements and low mobility (Liira et al. 2008). Disturbances associated with agricultural practices such as tillage, irrigation and the application of agrochemicals result in the loss of non-tolerant individuals. This influences species interactions (Begon et al. 2008) and may therefore lead to shifts in plant species assemblages in disturbed compared to natural habitat (Culpepper 2006, Kirchner 1977, Kleijn and Snoeiijing 1997). Commercial farming of maize occurs predominantly in the grassland biome in South Africa, while savanna is typically characterised by small-scale farming systems in rural communities. Also, grasslands in South Africa are typically found at higher elevations than savanna. This was consistent with the groupings for plant sampling points in the biplot.

From the results it is apparent that RSD points have a plant species composition that is not different to the RLD points. Furthermore, the RSD areas housed a minimal number of alien plant species comparable to the RLD area. This contradicts the notion that field margins of crop fields should gradually change from weedy, annual species to natural vegetation consisting of non-weedy, perennial species with increased distance from crop fields. It has been shown by Boutin and Jobin (1998) and Boutin et al. (2008) that weeds, annuals and alien plant species were more numerous in disturbed sites compared to more natural sites in agro-ecosystems, with more weedy species closer to crop field edges than further away. However, they found these changes to occur within 9–25 m from the crop fields.

As the RSD and RLD areas did not seem to differ significantly in terms of plant species composition, diversity or richness, our findings indicate that the ecotone, ecocline or edge effect hypotheses of crop fields is not applicable at larger scales. Obviously this becomes more pronounced towards the field edge. Piessens et al. (2006) found that edge effects of heathland vegetation were confined to the first 8 m outside the crop fields.

Furthermore, clustering of maize field points in the ordination suggest that the weed species composition of maize fields is very unique and few species are shared with rangelands. This is consistent with the results of Marshall (1989), as well as Marshall and Arnold (1995), which indicated that most perennial plant species of field margins are not adapted to establish successfully in crops and that species similarities between crop fields and field margins were in the order of 25–30 %. These patterns were attributed to low seed

dispersal into crop fields and fewer opportunities for germination due to cultivation activities. Our results show that RSD areas of the savanna shared only 6.23 % of plant species with maize fields. These included species such as *Urochloa panicoides*, *Cynodon dactylon*, *Euphorbia inaequilatera*, *Setaria verticillata*, *Panicum maximum* and *Phyllanthus parvulus*. Similarly, the RSD areas of the grassland shared 9.09 % of species with maize fields with shared species including *Commelina africana*, *Sporobolus africanus*, *Eragrostis gummiflva*, *Kyllinga erecta*, *Cynodon dactylon* and *Chloris virgata*. The distinct plant species composition of grassland and savanna maize fields may, therefore, be ascribed to the tendency of weeds to spread into crop fields from the surrounding vegetation (Leeson et al. 2005). Grassland and savanna habitats may contain different pioneer species able to spread into maize fields and it can be expected that maize fields situated in different biomes will have different weed communities.

The tendency of grassland localities to have tighter clustering of their rangeland sampling points seem to indicate that grassland localities have lower beta diversity (diversity between sampling points) than the savanna localities. Therefore, the savanna points had more unique plant species relative to the others when compared to grasslands. This is again possibly the result of the multi-structured nature of savanna, which, due to scattered woody plant species with specific climatic preferences, may lead to a greater between-plot variation in species (Schadek et al. 2009).

Arthropod diversity patterns

Arthropod communities in agro-ecosystems may be negatively affected by agricultural activities directly through the application of insecticides (De Snoo and De Wit 1998, Çilgi and Jepson 1995, Bundschuh et al. 2012) or indirectly via changes in the plant community (Feber et al. 1996). Our results indicated that arthropod species richness followed relatively similar trends to that for plants, and was therefore considerably higher in rangeland compared to maize fields. Arthropod diversity was also higher in rangeland, probably more as a result of the increased species richness than evenness. This indicates that an increase in the number of plant species lead to an increase in arthropod species numbers. These effects may be caused by several factors that are indirectly linked to plant species richness such as structural diversity, specific plant species composition, plant productivity and microclimate availability (Szinicz 2005). Nevertheless, rangelands are generally more heterogeneous than crop fields and provide opportunities for more arthropod species (Ingham and Samways 1996) which may lead to increased arthropod species numbers. This is in accord with numerous other studies that demonstrated increased arthropod species richness with increased plant species richness, e.g. Denys and Tscharrntke (2002), Hendrickx et al. (2007), Schellhorn and Sork (1997), Siemann et al. (1998).

These results reject our hypothesis that, due to possible disturbances associated with the maize fields, the RSD areas should have had lower arthropod species richness values compared to RLD areas. As with plant diversity and richness, negative effects on arthropods, if present, may be limited to the outer edge of the field. Similar studies conducted on arthropod diversity in crop fields and field margins did not sample arthropods in field margins further than 25 m from crop fields (Hendrickx et al. 2007; Szinicz 2005; Thomas and Marshall 1999). Taking our results into account, it is unlikely that any detectable effects on arthropod species richness exist beyond 30 m from maize fields. Unfortunately, the high mobility of most arthropods will inevitably complicate the detection of more permanent topological patterns for arthropod communities. Therefore, while crop production activities associated with maize fields may suppress arthropod numbers within

the rangeland, these individuals may soon be replaced by others from the adjacent vegetation. Therefore, further monitoring of arthropod communities over time will be required to confirm these trends.

Inconsistent with the results for plants however is the trends for arthropod species evenness across the gradient. The high evenness index values across the whole maize field–field margin gradient indicate that all arthropod morpho-species were relatively well represented and of equal proportions in both maize fields and rangeland, and therefore no obvious dominance effects occurred. This is contrary to what would be expected for the arthropod species evenness within crop fields. Evidence suggests that evenness or abundance of organisms at higher trophic levels is dependent on plant species richness and diversity (Murdoch et al. 1972; Pimentel 1961; Root 1973). On the contrary, our results indicate that little species dominance occurred among arthropods inside maize fields despite decreased plant species diversity. However, studies indicated that arthropod evenness or abundance is not necessarily a simple function of plant species richness but may depend on complex interacting factors such as plant species composition, productivity, vegetation structure, nutritional value, soil characteristics and agricultural management practices (Siemann 1998).

Overall, arthropod communities followed similar trends across the grassland and savanna biomes in terms of species richness, diversity and evenness. Therefore, it may be said that savanna and grassland arthropod communities responded in a similar fashion to the presence of maize fields.

In contrast to the results for plants, arthropod species richness was considerably higher in the grassland rangeland than in the savanna rangeland. It is uncertain whether this is a natural occurrence or as a result of sampling error. Since the efficiency of the D-vac method is influenced by vegetation structure (Elliott et al. 2006) woody vegetation in the savanna localities may have caused a decrease in sampling efficiency in the savanna habitats, which resulted in lower species richness values.

Arthropod species composition patterns

The CCA biplot for arthropods revealed that arthropod species assemblages were better explained by biome, altitude and type of farming practice (commercial vs. subsistence) than disturbances associated with the maize fields. This is in contrast to the results for plants. Most arthropods are highly mobile and readily travel between maize field and natural habitats (Alomar et al. 2002, Garibaldi et al. 2011, Norris and Kogan 2000). Therefore, the effect of disturbance may be reduced if individuals are constantly able to move to suitable habitats inside a particular maize field-rangeland environment. On a larger scale however, the distinctive climatic conditions (and vegetation) associated with a biome and particularly altitude, may influence the composition of arthropod species that are able to persist in that agricultural environment.

Similar to the results for plant species assemblages, the presence of maize fields did not have a detectable effect on species composition of arthropods in RSD sites as it was found to have a very similar species composition to the RLD sites. However, clear differences could be observed between maize fields and rangelands in terms of arthropod species composition, supporting the notion that arthropod species may be characterised based on their preference for habitat (cultivated or natural) (Duelli and Obrist 2003). Therefore, some species may be characterised as being crop field or cultural species, while others may be typical of an ecotone or undisturbed natural habitat (Duelli and Obrist 2003). This is also consistent with the results of Kiss et al. (1997) who found that while almost twice as

many predatory carabid beetles species occurred in field margins compared to crop fields, some are typical ‘field species’ unique to the crop fields either within certain periods or throughout their lifecycle. As maize fields represent unique environments, this may allow for only a few specialized species to persist. For example, the high fecundity of aphids (Hemiptera: Aphididae) allow them to successfully populate ephemeral habitats such as annual crops where others cannot (Wissinger 1997). Furthermore, it was found that the grassland and savanna had distinct arthropod communities. This was true not only for the rangelands, but also for maize fields. Schaffers et al. (2008) and Symstad et al. (2000) also indicated that arthropod species composition is largely determined by plant species composition. As grassland and savanna had very distinct plant communities, this may also have resulted in the distinct arthropod communities. Furthermore, distinctions between grassland and savanna maize field arthropod communities agree with findings that crop fields are colonized by arthropods from the surrounding field margins (Alomar et al. 2002; Norris and Kogan 2000). Since it has been shown that grassland and savanna rangelands contained distinctive arthropod communities, it would be expected that maize fields will also have unique species associated with the particular biome in which the maize field is located.

The certain degree of overlap in arthropod species between maize fields and rangeland of the savanna biome may be an indication that arthropod communities of the savanna biome have a greater affinity for maize fields than the arthropod communities of the grassland biome. Vegetation structure is considered to be one of the major factors that shape arthropod communities (Strong et al. 1984). Since maize is a grass species it may be said that maize fields are, in effect, man-made grasslands. It would therefore be expected that grassland arthropods should have had a greater affinity for maize fields than savanna arthropods, especially since maize fields rarely contain woody plant species. However, maize fields do not mimic the low-growing structure of grassland, but have much taller plant growth (\pm 1.5–2.2 m) with bigger leaves and thicker stems. Therefore, the vegetation structure of a maize field resembles a savanna or woodland habitat more closely than a grassland habitat, and attracts savanna arthropods.

Clustering of arthropods was not as clearly defined as for plants, and maize fields shared many more arthropod species with rangeland than plant species. This is consistent with the results of Procheş and Cowling (2007) that attributed this phenomenon to the high mobility of most arthropod species. Since arthropods are able to move freely between habitats, it is expected that clustering of sample points of arthropod species will be less well defined than for plants.

Conclusion

This study described for the first time the plant and arthropod species composition and diversity patterns along a maize field–field margin gradient in grassland and savanna biomes of South Africa. Overall, the results indicated that the patterns of plant and arthropod diversity, richness and evenness followed similar trends for maize field–field margin gradients across the two biomes of South Africa. Plant and arthropod diversity were constantly found to be lower inside maize fields than in rangelands. However, from the results it is shown that rangeland diversity is not significantly affected by the presence of maize fields, as RSD areas did not have significantly lower plant and arthropod diversity values than RLD areas. This effect was consistent across biomes.

In addition to biodiversity patterns, this study also compared the species assemblages of plants and arthropods in maize agro-ecosystems of South Africa. Our results indicated that the main predictor of plant species assemblages were agricultural disturbances, while biome, altitude and, to a lesser extent, farming practice are better predictors of arthropod species composition. Overall, the species assemblage patterns for plants and arthropods were in accord with the results for the diversity patterns, with distinct communities in maize fields and rangeland, but little difference in species composition between the RSD and RLD areas within the rangeland. Therefore, our first and second hypothesis are not supported, as our results suggest that the possible disturbance effects of maize fields do not have considerable negative effects on either the diversity or species assemblages of plant and arthropod communities in grassland and savanna habitats at ≥ 30 m from the area of active cultivation. Further studies will be required to establish the distances at which significant changes do occur.

Furthermore, we proposed that the multi-layered vegetation structure of the savanna biome should enable it to contain a higher plant and arthropod diversity than the grassland biome. Overall, our results indicated that savanna tended to have significantly higher plant species richness (although not diversity or evenness) than the grassland biome in natural rangeland. Results were inconclusive for arthropods. Therefore the third hypothesis is partially supported in terms of plant species richness.

Analyses of plant and arthropod species compositions across maize field–field margin gradients indicated that arthropod communities does seem to be defined by the biome in which they are found, if not as clearly as for plant communities. Plant species assemblages were however better defined than arthropod species assemblages, and this agrees with Procheş and Cowling (2007) regarding arthropod assemblages across biomes. Furthermore, our ordination analyses did not contain enough conclusive evidence to support our fourth hypothesis stating that maize fields have lower beta diversity compared to natural environments.

These results indicate that crop field margins at distances of 30–100 m are not merely disturbed, non-functional ecosystems but are surprisingly rich in plant and arthropod diversity. Therefore, these sites may be of real conservation value in the agricultural landscape, especially since an increasing portion of arable land is being transformed into crop agro-ecosystems. In future it may be useful to survey sites closer to maize fields (< 30 m) to determine the distance at which significant impacts on plant and arthropod communities do occur in South Africa, if at all. The focus of this study was mainly on trends of total plant and arthropod diversity and further analyses are required to determine responses of plant and arthropod taxa at family and functional group level. Ultimately, this research will contribute towards a baseline for biodiversity monitoring and could aid in quantifying the conservation value of field margins.

Acknowledgments This work formed part of the Environmental Biosafety Cooperation Project between South Africa and Norway, coordinated by the South African National Biodiversity Institute. Financial support was also provided by GenØk-Centre of Biosafety, Norway, Norad project GLO-3450.

Appendix

Tables 4, 5, 6, 7, 8 and 9.

Table 4 Hierarchical Linear Modelling (HLM) analysis for differences in plant and arthropod richness and diversity index values between biomes (grassland and savanna) for distance from maize field (m) and interactions (between biome and distance)

	Fixed effects plants			Fixed effects arthropods		
	Biome	Distance	Biome × distance	Biome	Distance	Biome × distance
Species richness						
df	18.159	114.660	114.660	17.711	113.818	113.818
F	11.210	41.016	2.771	1.486	8.964	1.450
p	0.004*	0.000*	0.021*	0.239	0.000*	0.212
Margalef’s species richness index						
df	17.904	114.367	114.367	17.640	113.783	113.783
F	9.088	30.184	2.683	0.764	9.544	0.613
p	0.007*	0.000*	0.025*	0.394	0.000*	0.690
Shannon–Wiener diversity index						
df	17.208	114.595	114.595	16.656	113.298	113.298
F	6.997	55.149	1.232	0.039	6.134	0.248
p	0.017*	0.000*	0.299	0.847	0.000*	0.940
Simpson’s diversity index						
df	16.658	115.414	115.414	132.000	132.000	132.000
F	2.114	35.525	0.706	3.355	2.038	0.374
p	0.165	0.000*	0.620	0.069	0.077	0.866
Pielou’s evenness						
df	132.000	132.000	132.000	15.311	112.237	112.237
F	0.352	28.567	1.073	3.877	0.624	0.438
p	0.554	0.000*	0.378	0.067	0.681	0.821

df degrees of freedom, F F value, p p value

* Significant p values at p < 0.05

Table 5 Effect sizes of Hierarchical Linear Modelling (HLM) analysis for comparisons between distances from maize field in terms of mean plant diversity index values

Distance class comparison	Species Richness	Margalef’s species richness	Shannon–Wiener diversity index	Simpson’s diversity index	Pielou’s evenness
MF1 x MF2	0.126	0.099	0.107	0.040	0.114
MF1 x RA1	2.028**	1.63**	2.605**	2.210**	1.861**
MF1 x RA2	2.107**	1.711**	2.862**	2.310**	2.131**
MF1 x RA3	2.181**	1.900**	2.876**	2.430**	2.139**
MF1 x RA4	1.967**	1.697**	2.684**	2.330**	2.052**
MF2 x RA1	1.902**	1.528**	2.498**	2.170**	1.975**
MF2 x RA2	1.980**	1.613**	2.755**	2.270**	2.245**
MF2 x RA3	2.054**	1.801**	2.769**	2.390**	2.253**
MF2 x RA4	1.841**	1.598**	2.577**	2.290**	2.166**
RA1 x RA2	0.079	0.084	0.257	0.100	0.270

Table 5 continued

Distance class comparison	Species Richness	Margalef's species richness	Shannon–Wiener diversity index	Simpson's diversity index	Pielou's evenness
RA1 x RA3	0.153	0.273	0.270	0.220	0.278
RA1 x RA4	0.061	0.070	0.078	0.120	0.191
RA2 x RA3	0.074	0.189	0.014	0.120	0.008
RA2 x RA4	0.140	0.014	0.179	0.020	0.079
RA3 x RA4	0.214	0.203	0.192	0.100	0.087

MF1 and MF2, maize field; RA1 and RA2, rangeland (30–100 m); RA3 and RA4, rangeland (100–400 m)
Significance codes: ** large effect at $d \geq 0.8$; * medium effect at $d \geq 0.5$

Table 6 Significant interaction effects between biome and distance from maize field in terms of plant species richness and Margalef's species richness index values

Distance class comparison	Species richness	Margalef's species richness
Grassland		
MF1 x MF2	0.079	0.057
MF1 x RA1	1.326**	1.011**
MF1 x RA2	1.902**	1.523**
MF1 x RA3	1.963**	1.599**
MF1 x RA4	1.474**	1.128**
MF2 x RA1	1.247**	0.954**
MF2 x RA2	1.823**	1.466**
MF2 x RA3	1.884**	1.542**
MF2 x RA4	1.396**	1.071**
RA1 x RA2	0.576*	0.512*
RA1 x RA3	0.637*	0.587*
RA1 x RA4	0.148	0.116
RA2 x RA3	0.061	0.075
RA2 x RA4	0.427	0.396
RA3 x RA4	0.488	0.471
Savanna		
MF1 x MF2	0.174	0.141
MF1 x RA1	2.730**	2.243**
MF1 x RA2	2.312**	1.899**
MF1 x RA3	2.399**	2.202**
MF1 x RA4	2.460**	2.266**
MF2 x RA1	2.556**	2.102**
MF2 x RA2	2.137**	1.759**
MF2 x RA3	2.224**	2.061**
MF2 x RA4	2.285**	2.126**
RA1 x RA2	0.419	0.344
RA1 x RA3	0.331	0.041
RA1 x RA4	0.270	0.023

Table 6 continued

Distance class comparison	Species richness	Margalef's species richness
RA2 x RA3	0.087	0.302
RA2 x RA4	0.148	0.367
RA3 x RA4	0.061	0.065

MF1 and MF2, maize field; RA1 and RA2, rangeland (30–100 m); RA3 and RA4, rangeland (100–400 m). Bold text indicates key differences between biomes

Significance codes: ** large effect at $d \geq 0.8$; * medium effect at $d \geq 0.5$

Table 7 Effect sizes of Hierarchical Linear Modelling (HLM) analysis for comparisons between grassland and savanna in terms of mean index values at similar distances from maize field

Survey	Species richness	Margalef's species richness	Shannon–Wiener diversity index	Simpsons diversity index	Pielou's evenness
Plants					
MF1	0.477	0.378	0.531*	0.042	0.435
MF2	0.573*	0.461	0.793*	0.647*	0.543*
RA1	1.881**	1.609**	1.273**	0.678*	0.380
RA2	0.887**	0.754*	0.171	0.103	0.480
RA3	0.913**	0.981**	0.187	0.032	0.307
RA4	1.462**	1.517**	0.772*	0.357	0.022
Arthropods					
MF1	0.155	0.130	0.169	0.168	0.229
MF2	0.182	0.098	0.309	0.480	0.529*
RA1	0.696*	0.513*	0.148	0.048	0.327
RA2	0.633*	0.421	0.082	0.656*	0.886**
RA3	0.635*	0.488	0.108	0.371	0.624*
RA4	0.641*	0.389	0.032	0.205	0.320

MF1 and MF2, maize field; RA1 and RA2, rangeland (30–100 m); RA3 and RA4, rangeland (100–400 m)

Significance codes: ** large effect at $d \geq 0.8$; * medium effect at $d \geq 0.5$

Table 8 Adonis analysis, with nestedness of data in a transect taken into account, indicating significance of separation between treatments within biome for both plant and arthropod groups based on species composition

Survey	df	F	R	p
Plants				
Biome	1	13.526	0.068	0.001*
Treatment	2	19.810	0.198	0.001*
Biome × Treatment (interaction)	2	4.278	0.043	0.001*
Residuals	138	–	0.691	–
Arthropods				
Biome	1	6.007	0.039	0.001*
Treatment	2	2.513	0.033	0.001*
Biome × Treatment (interaction)	2	1.777	0.023	0.001*
Residuals	138	–	0.904	–

df degrees of freedom, F F value, R R value, p p value

Table 9 Effect sizes of Hierarchical Linear Modelling (HLM) analysis for comparisons between distances from maize field in terms of mean arthropod diversity index values

Distance class comparison	Species richness	Margalef's species richness	Shannon–Wiener diversity index	Simpson's diversity index	Pielou's evenness
MF1 x MF2	0.008	0.017	0.041	0.155	0.140
MF1 x RA1	0.623*	0.727*	0.918**	0.699*	0.248
MF1 x RA2	0.542*	0.580*	0.462	0.189	0.126
MF1 x RA3	0.537*	0.588*	0.731*	0.552*	0.163
MF1 x RA4	0.666*	0.771*	0.966**	0.629*	0.237
MF2 x RA1	0.630*	0.745*	0.877**	0.544*	0.107
MF2 x RA2	0.549*	0.598*	0.421	0.033	0.267
MF2 x RA3	0.545*	0.605*	0.690*	0.397	0.022
MF2 x RA4	0.673*	0.788*	0.925**	0.474	0.097
RA1 x RA2	0.081	0.147	0.456	0.511*	0.374
RA1 x RA3	0.086	0.140	0.188	0.147	0.085
RA1 x RA4	0.043	0.044	0.048	0.070	0.010
RA2 x RA3	0.005	0.007	0.268	0.364	0.289
RA2 x RA4	0.124	0.191	0.504	0.441	0.364
RA3 x RA4	0.129	0.183	0.235	0.077	0.075

MF1 and MF2, maize field; RA1 and RA2, rangeland (30–100 m); RA3 and RA4, rangeland (100–400 m)
Significance codes: ** large effect at $d \geq 0.8$; * medium effect at $d \geq 0.5$

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