Small-scale traditional maize farming fosters greater arthropod diversity value than conventional maize farming

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Abstract
Globally insects are in decline, with the transformation of natural areas for agriculture one of the most important drivers of this decline. Yet, insects play an important role in regulating ecosystem services such as pollination, soil fertility and pest suppression, so their conservation within agricultural areas is critical. We examined comparative impacts of traditional small-scale low input farming versus large-scale conventional farming systems, and mono-cropped versus intercropped systems in Kenyan maize fields on predator, ant and herbivore arthropod species richness and composition. We also considered the value of hedgerows and percentage of surrounding maize cover for arthropod conservation. As expected, traditional farming retained higher herbivore species richness, evenness and abundance, as well as higher predator abundance compared to conventional farming. Percentage maize cover was positively correlated to ant species richness, predator and herbivore abundance, as well as determining species assemblage composition for ants and herbivores. Hedgerow volume and the comparison of mono- vs inter-cropping were important predictors for predator evenness. These results suggest that the low input farming systems retain far higher arthropod numbers, although this does not seem to be due to the use of intercropping on the farms. Rather it seems that hedgerows play an important role in maintaining arthropods. While higher maize coverage surrounding the farm increases the species and abundance of arthropods in the fields, this is most likely due to the high biotope fidelity of arthropods that specialize in open cropping systems such as maize fields.

Implications for insect conservation
The results here are encouraging as the retention of culturally important farming techniques (i.e., the traditional Kenyan farmers) and small improvements, such as the retention of hedgerows, greatly promotes biodiversity in the farmlands.

Keywords
Agroecology · Arthropod diversity · Herbivores · Kenya · Predators · Subsistence farming · Sub-Saharan Africa

Introduction
Arthropod populations are declining globally (Cardoso et al. 2020), with land transformation due to agriculture and the direct impacts of agriculture a major contributor to these declines (Sánchez-Bayo and Wyckhuys 2019). Agriculture is also isolating remnant natural patches and causing further declines due to habitat fragmentation (Fahrig 2017) and metapopulation breakdowns (Hanski 1998). This leads to the simplification of the agricultural systems and in turn the ecosystem services provisioned (Cardoso et al. 2020). To counter these impacts land sparing and sharing approaches are required (Phalan et al. 2011; Balmford et al. 2019; Samways et al. 2020).

Surrounding landscapes are an important consideration for biodiversity within crops (Macfadyen et al. 2011), as this can have benefits for ecosystem services such as pest suppression (Aristizabal and Metzger 2018), although this is not always the case (Fischer et al. 2004). Such practices shape structural configurations and edaphic qualities of the cropland environment, leading to food resource dynamics that additionally determine arthropod community structures and trophic interactions (Albajes et al. 2009; Habel et al. 2019). Through the intermediate landscape complexity hypotheses, we can predict that landscapes of intermediate complexity, with natural or semi-natural vegetation within the landscape,
has greater biodiversity benefit than very complex or simple landscapes (Tscharntke et al. 2012). This has been found to be true in Europe (Concepción et al. 2008; Cormont et al. 2016) and East Africa (Midgea et al. 2014). Conceptually similar to this, neighbouring vegetation in South Africa has a greater effect for conventional citrus orchards compared to organic orchards (Galloway et al. 2021). This seems to be due to organic orchards already having high levels of biodiversity with little room to improve. On the other hand, local practices including chemical interventions against crop pests, weeds and diseases negatively affect quality of arthropod habitats (Roubos et al. 2014), while cropping regimes influence temporal fluxes in arthropod food resources.

Other cropping characteristics such as crop-field geometric shapes and patterns, and densities of ground cover, influence arthropod aggregations and assemblages across farmlands. For instance, field-scale mixed cropping or farm-wide crop diversity promote higher heterogeneity, which is beneficial in attracting higher populations and diverse species of predators (Weibull et al. 2003; Bianchi et al. 2006). Semi-natural margins and hedgerows are also important as refuges, breeding or hibernation habitat for such predators as spiders or for parasitoids (Haaland et al. 2011; Gaigher et al. 2016), because they remain undisturbed for longer time-frames than do most crops (Rusch et al. 2010). Conversely, widely-spaced crops planted on large monoculture landscapes may be more attractive to crop pests and increase the risk of pest outbreak due to the consequent limit in food resource options for such herbivores (Rusch et al. 2016).

Within the African context there is not much literature on biodiversity within maize fields. Much of what is known is from South Africa, where maize margins up to 30 m were surprisingly biodiverse, suggesting limited spillover from the local landscape (Botha et al. 2015), especially for predators (Botha et al. 2018). In East Africa, most work has concentrated on the suppression of pest species using push–pull technology. This involves the planting of intercrops that are known to repel insect pests (Khan et al. 1997) and is both effective in controlling pest species (Midega et al. 2018) and promoting in-crop arthropod diversity (Midega et al. 2008). In fact, Kenyan maize fields have been shown to have top-down suppression of herbivoruous arthropods on traditionally farmed maize fields (Otieno et al. 2019a).

It is more economically beneficial for traditional small-scale farmers to utilise agronomic strategies that limit populations of pests or weeds on croplands and avoid use of expensive pesticides (Tscharntke et al. 2012). This involves reduced or discontinuation of chemical agents in pest and weed management; application of farmyard and crop residues; intercropping; crop rotation, and occasional land following (Rosa-Schleich et al. 2019). This strategy is widely recognised as a form of conservation agriculture which is beneficial for both environmental integrity and reducing cost of farming (Norton et al. 2009; Gomiero et al. 2011; Sain et al. 2017). Furthermore, it benefits local conservation efforts as it makes the croplands more permeable to native arthropods and so reduces the isolation of populations in remnant patches (Theron et al. 2020).

The aim of this study was to determine the role that farming intensity (low impact traditional vs high impact commercial conventional farming), intercropping (mono- vs intercropping), the surrounding landscape (through percentage maize cover and volume of hedges) and their interaction, have on promoting arthropod diversity. We have done this for the predator, herbivore and ant assemblages separately as well as for the two sampling seasons (the long and short rains) combined and independently. We expect the lower intensity farming systems (traditional and intercropping) to have the highest arthropod species diversity due less pesticides in the system and promotion of available resources. We may see more benefit from hedge rows, intercropping and the surrounding landscapes in conventional maize fields as traditional farming systems already support high biodiversity. Interactions between landscape (maize cover) and farming intensity would likely be due to greater benefits for conventional farms from the surrounding landscapes (Galloway et al. 2021).

Materials and methods

Study area

The study was based in Kakamega Country, Kenya, located between 00°11’09” N and 00°26’08” N and between 34°44’30” E and 34°58’48” E (Fig. 1), across a small-scale agricultural landscape dominated by non Bt-maize (Zea mays L.) fields interspersed with human settlements, riverine habitat and isolated patches of semi-natural or uncultivated scrub and bush (Garcia et al. 2009). Maize may be grown in monocultures alongside or inter-cultured with a range of other semi-annual crops such as legumes, pulses or vegetables. The most popular legumes for inter-cropping maize in Kakamega County are beans Phaseolus sp. (Fabaceae) and peas Vigna sp. (Fabaceae). The rainfall ranges from 1200 to 2000 mm annually with bimodal distribution, the more intensive rain season occurring between March and May (long rains) and a lighter one from August/September to October/November (short rains), while mean annual temperature is 21.4 °C (Kenya Meteorological Department 2017). Nearly all farmers grow maize in both rainy seasons. In addition to maize and legumes, the general landscape consists of banana groves, small tree stands or woodlots, steams, and the occasional small sugarcane plantation. Due to high human population density, there is hardly any perennially unused land.
Farmers on the low impact traditional farms grow crops primarily for their own subsistence and limited sales to the local community. These farmers apply only non-synthetic fertilizers such as livestock manure and crop residues which additionally improve soil structure (Eden et al. 2017). They plant multiple crops which are frequently inter-cropped and at times rotated across plots, occasionally they leave the land fallow during some seasons, and maintain indigenous hedgerows and woodlots on the farm. They also tend to keep livestock or poultry. Many of these practices have been inherited from earlier generations but are increasingly also being recognized by farmers as useful in strategically adapting to adverse effects of erratic weather conditions and declining soil qualities due to earlier intensive inorganic fertilization (Ministry of Agriculture Livestock and Fisheries 2016). Conversely, those who practice conventional farming tend to have larger croplands, predominantly apply synthetic fertilizers to grow crops in un-rotated mono-cultures, maintain few hedgerows, allow no fallows nor uncultivated patches and are less likely to keep livestock.

Farm selection and topology environmental variables

Farms were selected on the basis of three main typological characteristics: presence of maize (no farms selected used Bt maize); maize farming system (traditional methods versus those practising conventional methods); and cropping methods (those on which maize is inter-cropped versus those with mono-cultured maize). Thus 16 farms were selected randomly, of which nine were small scale and traditionally farmed and seven conventional, and nine had maize inter-cropped with legume crops while seven were maize mono-crop fields (Otieno et al. 2019a, b). An effort was made to include conventional intercropped and traditional monocropped farms. Thus, the traditional farms here were not necessarily also mixed-cropped (Fig. 1; Supplementary Table 1) and farming type and cropping system are uncorrelated (Spearman’s correlation co-efficient = 0.24). The selected farms, which ranged from 0.6 to 9 (mean = 3.2; SD ± 2.62) hectares, were also characterised by whether they
were predominantly surrounded by indigenous or exotic live hedgerows. Spatial independence of samples was ensured by maintaining a minimum of about 500 m inter-farm distance (Beecher et al. 2002). Although this is within the flight range of the most mobile species, sites were independent once a spatial random effect was added (see data analyses for details). The farm variables recorded were farming system, cropping method, farm size, hedgerow type and volume, as well as percentage maize in a 500 m buffer. These were recorded during the first field visit in October 2015, with the exception of the 500 m buffer, which was digitised later using Google Earth images from January 2016. Percent maize cover was estimated as proportion of maize crop in a 500 m buffer around the sampling point. This was achieved by using a Google Earth satellite image imported into QGIS 3.12.3 (https://www.qgis.org/). Maize field were identified from the image and through local knowledge and a shape file created. The amount of maize cover that intercepted the 500 m buffer was calculated and compared to the total area of the buffer to get percentage maize cover. Hedges were made up of several species and each farm had unique hedgerow composition. We were able to record if the hedges were mainly indigenous or exotic. Hedgerow measurements were determined using a 100-m tape measure and a metre rule. Hedgerows were measured for total length, as well as height and width, which were both determined at intervals of 20 m along each side of the farm. Volume was chosen rather than length to quantify available hedgerow due to the frequent variations in thickness, heights and shapes of many hedges in the study area, and also due to variations in their species composition (see Litza and Dickmann 2020).

**Arthropod sampling**

Arthropod sampling was undertaken in all maize fields during two maize cropping seasons, twice in the less intensive rainy season in October 2015–January 2016 (short rains) and twice in the more intensive rainy season between April and July 2016 (long rains). Arthropod samples were collected using both standard sweep nets and un-baited pitfall traps. Pitfall traps consisting of 70 mm diameter and 120 mm high plastic cups and buried with rims flush with ground surface, and filled to one-third with 25% sodium chloride solution, with a conical plastic shield erected above the traps to guard against rain (Brown and Matthews 2016; Otieno et al. 2019a). Four traps were placed on each farm placed along a randomly selected diagonal line running across each farm, and the traps were collected after 3 days. Traps were placed at equal intervals along the diagonal line and was at least 15 m from field margins and each other. Four traps were laid out twice per season per farm resulting in 256 traps in total. When it rained and the run-off filled the traps with soil, the affected samples were discarded and traps re-set. Insects on maize were sampled using 200 sweeps of a 40 cm diameter sweep net, walking straight and brisk and sweeping once on one side for each forward step and on the other side for the following step. Where a farm was too short for 200 sweeps, the remaining sweeps were taken along multiple transects. All sweeps were restricted to the maize fields and included field edges due to the small size of some fields. During trap collection, arthropod samples were collected by Girard et al. (2011), before being sent to the laboratory. In the laboratory, arthropods were sorted and identified to species or morphological species (Samways et al. 2010) except spiders, which were identified to Order. Arthropods were also grouped into either of two broad feeding guilds: predominantly predacious (secondary and tertiary consumers) or predominantly herbivorous (primary consumers). Species richness, evenness (Shannon’s entropy), abundances and the assemblage composition were determined.

**Data analyses**

All data analysed were performed using the R software version 4.0.4 (R Core Team 2021). Hedgerow volume was determined as a function of total length, mean height and mean lateral width: \( V = L(W^*H)/n \) where \( V \) = volume; \( L \) = total length of living vegetation in the hedgerow around the farm; \( W \) = lateral width of hedgerow at each 20-m interval; \( H \) = height of hedgerow at each 20-m interval; \( n \) = total number of intervals.

Arthropod sampled from the two sampling methods (sweep nets and pitfall traps) were pooled and analysed together. As ants are polyphagous and have highly variable abundance, we analysed them separately. Species rarefaction was done for species found on conventional and traditional farms during the long and short rains separately using the iNext package (Chao et al. 2014; Hsieh et al. 2020). Species estimators (Chao and Jackknife2) were calculated in the vegan package (Oksanen et al. 2019). The influence of farming system (traditional versus conventional farming), cropping system (mono- or intercropping), hedgerow type (exotic versus indigenous), hedgerow volume, percentage maize cover and farm size (Supplementary Table 1) on predator and herbivore species richness, evenness and abundance were performed using linear mixed models and model averaging. Prior to analyses, we rescaled all variables and then we checked for multicollinearity using the variance inflations factors (VIF) in the package car (Fox and Weisberg 2019). Once farm size was excluded no variable had a VIF > 2. Shannon’s entropy was calculated for all three assemblages (ant, predator and herbivore) using the hillR package (Li 2018). Ant, predator and herbivore species richness fitted a Poisson distribution and abundance a negative binomial distribution when plotted with quantile–quantile plots.
We tested for spatial autocorrelation using a Mantel test, which showed no spatial autocorrelation effect and spatial random effects did not improve a correlogram, using the package ncf (Bjørnstad 2020), thus for simplicity of the models we excluded a spatial random effect (Bolker et al. 2009). All models with Poisson distributions were tested for overdispersion using the AER package (Kleiber and Zeileis 2008). For ant, predator and herbivore species richness and abundance, a global linear mixed model was created with the five predictors above, as well as the interaction between farming system x intercropping and the interaction between farming system x maize cover in the lme4 package (Bates et al. 2015). All combinations of the predictor variables were then ranked for best fit, based on the AICc criteria using the dredge function in MuMIn. The best fitting model and models with ΔAICc of ≤ 6 were used in model averaging (Burnham and Anderson 2002). The values of the parameters were estimated by conditional model averaging of the best model subset using the model.avg function in the MuMIn package in R (Bartoń 2019). We calculated R² values for each model using the r.squared GLMM function in MuMIn (Bartoń 2019).

To analyse the changes in similarity of the ant, predator and herbivore assemblages due to the five predictors above and the interactions between farming system × intercropping and farming system × maize cover, we used the manyglm function within the mvabund package (Wang et al. 2012). These analyses create a multiple variate space by fitting a single generalised linear model (GLM) to the abundance of each species across sites. Community responses are then calculated through resampling (Wang et al. 2012). This function fits multiple generalized linear models on all combinations of variables between a community and environmental data set, thus allowing effects to be identified at the assemblage level (Wang et al. 2012). These analyses were calculated with the predictor’s response assumed to be correlated via ridge regularization (using the “shrink” parameter). All these multivariate models were fitted with negative binomial distribution, assuming a quadratic mean–variance. Test statistics were calculated based on the “pit-trap” resampling method with 999 permutations (Wang et al. 2012). R² values were calculated using the best.r.sq function in mvabund. Multivariate abundance data were further analysed with the Boral (Hui 2016) package. This produces model-based analyses using Bayesian Markov Chain Monte Carlo estimation methods (Hui 2016). This approach creates an unconstrained ordination and makes use of pure latent variable models, for ordinations with and without the influence of environmental variables (Hui 2016).

**Results**

A total of 2827 individual arthropods were sampled from 199 arthropod species or morphospecies comprising 15 orders that belonged to 51 families (see Supplementary Table 2). Of these, 2061 individuals were predatory, comprising of 121 species and 26 families, while 766 were herbivores from 78 species and 32 families. The pitfall traps captured a total of 61 species and 761 individuals (3.1 species and 17.9 individuals per trap), while sweepnetting captured a total of 140 species and 2 066 individuals (21.8 (SD ± 7.9) species and 129.1 (SD ± 62.3) individuals per farm). The most abundant orders were Hymenoptera with 1 467 individuals from 86 species and morphospecies and 11 families; Orthoptera with 370 individuals from 25 species/morphospecies and 5 families; and Coleoptera with 353 individuals from 59 species and 20 families. The most abundant families were Formicidae (Hymenoptera) with 1 399 individuals (60 species and morphospecies); Gryllidae (Orthoptera) with 275 individuals (3 species and morphospecies); and Acrididae (Orthoptera) with 86 individuals (18 species and morphospecies). Species accumulation curves suggest a nearing asymptote, with greatest species richness in the traditional farms during the long rains (Fig. 2). Traditional farms have higher predator, ant and herbivore observed, rarefied and estimated species richness when compared to conventional farms (Fig. 2; Supplementary material 3).

Ant species richness was positively correlated to percentage maize cover (Fig. 3a), although this was primarily driven by ants in the conventional farms (Table 1, Fig. 3b). Both ants and herbivores show significantly positive response to
increase maize during the long rain season, with a positive correlation in conventional farms and a negative correlation on traditional farms (Table 1, Supplementary material 4). Herbivore species richness and evenness was highest in traditional farms compared to conventional farms for all seasons and just for richness during the long rains (Table 1, Fig. 3c, f). Predators and ants during the long rains showed a significant preference for mixed crops, while ants also had significant interaction between farming system and maize cover, as well as farming system and cropping system (Table 1). Predator Shannon’s entropy scored higher in mixed cropping systems than those that were mono-cropped, as well as having a positive correlation to hedge volume (Table 1, Fig. 3d). During the short rains, predators species richness and evenness showed a significantly positive correlation to hedge volume (Table 1; Supplementary material 4).

Abundance was positively correlated with percentage maize cover for predators and herbivores overall and for predators and ants during the long rains (Table 1, Fig. 4a, e, Supplementary material 4). Ant abundance only positively

![Ant species richness](image1.png)

![Ant species richness](image2.png)

![Herbivore species richness](image3.png)

![Predator evenness](image4.png)

![Predator evenness](image5.png)

![Herbivore evenness](image6.png)

Fig. 3 Significant response of species richness and evenness to the environmental variables (Table 1). Ant species richness in response to percentage maize (a); percentage maize and the interaction with farming type (black line and dot represent conventional farming, grey dots and dashed line represents traditional farming) (b); Herbivore species richness and farm type (traditional (Trad) versus conventional (Conv)) (c); Predator evenness (Shannon's entropy) and cropping system (monoculture of maize (mono) vs a mixed cropping system (mixed)) (d); and hedge row volume (m³) (e); and herbivore evenness and farm type (traditional (Trad) versus conventional (Conv)) (f)
responded to maize cover on traditional farms and not conventional farms. Traditional farms had higher abundances of predators and herbivores than conventional farms for both seasons combined and for the short rains, while ants and herbivores showed higher abundance during the long rains (Fig. 4b, f, Supplementary materials 4). Predator abundance was only higher in mixed cropping on conventional farms (Fig. 4c).

Table 1 Results of model averaging for the top performing models (ΔAICc < 6) using conditional averaging for the species richness (Poisson distribution), evenness using Shannon’s entropy value (Hill number q = 1; Gaussian distribution) and abundance (negative binomial distribution) for arthropod predators, ants and herbivores compared to environmental predictors.

|                | R²      | %Maize | Farming type | Crop system | Hedge type | Hedge volume | Farm × %maize | Farm × crop |
|----------------|---------|--------|--------------|-------------|------------|--------------|---------------|-------------|
| **Both seasons** |          |        |              |             |            |              |               |             |
| Species richness |         |        |              |             |            |              |               |             |
| Predators      | 0.72    | 1.59   | 1.74         | 1.82        | 1.18       | 1.56         | 1.87          | 0.29        |
| Ants           | 0.65    | 2.31*  | 1.39         | 1.32        | 1.17       | 1.57         | 2.69**        |             |
| Herbivores     | 0.68    | 1.91   | 2.74**       | 0.13        | 1.25       | 1.76         | 1.42          |             |
| Evenness       |         |        |              |             |            |              |               |             |
| Predators      | 0.82    | 0.47   | 1.83         | 2.93**      | 0.22       | 4.06***      | 1.12          |             |
| Ants           | 0.44    | 0.73   | 1.15         | 1.11        | 0.71       | 0.68         | 1.60          |             |
| Herbivores     | 0.58    | 0.24   | 2.78**       | 0.48        | 1.81       | 0.20         |               |             |
| Abundance      |         |        |              |             |            |              |               |             |
| Predators      | 0.19    | 2.70** | 2.22*        | 1.34        | 1.18       | 0.77         | 0.47          | 2.25*       |
| Ants           | 0.19    | 1.17   | 1.27         | 0.33        | 0.78       | 1.83         | 2.01*         |             |
| Herbivores     | 0.27    | 3.47***| 3.92***      | 1.25        | 1.32       | 0.44         | 0.82          | 1.26        |
| **Long rains** |          |        |              |             |            |              |               |             |
| Species richness |       |        |              |             |            |              |               |             |
| Predators      | 0.74    | 1.05   | 0.50         | 2.66**      | 0.50       | 0.02         | 1.32          |             |
| Ants           | 0.89    | 3.15** | 1.62         | 2.08*       | 1.13       | 2.98**       | 2.26*         |             |
| Herbivores     | 0.85    | 2.17*  | 2.60**       | 1.16        | 0.14       | 1.12         | 1.87          | 1.64        |
| Evenness       |         |        |              |             |            |              |               |             |
| Predators      | 0.63    | 0.59   | 1.22         | 1.66        | 0.73       | 0.91         | 1.27          |             |
| Ants           | 0.56    | 0.76   | 1.42         | 1.16        | 1.04       | 0.56         | 1.52          | 1.08        |
| Herbivores     | 0.36    | 0.47   | 0.75         | 0.67        | 1.02       | 1.53         |               |             |
| Abundance      |         |        |              |             |            |              |               |             |
| Predators      | 0.46    | 1.71   | 1.29         | 2.67**      | 1.32       | 0.79         | 1.55          | 1.70        |
| Ants           | 0.40    | 5.01***| 2.80**       | 1.70        | 0.94       | 1.33         | 3.14**        | 2.01*       |
| Herbivores     | 0.57    | 3.31***| 2.24*        | 2.86**      | 1.24       | 1.59         | 2.68**        |             |
| **Short rains**|          |        |              |             |            |              |               |             |
| Species richness |       |        |              |             |            |              |               |             |
| Predators      | 0.59    | 0.58   | 2.26*        | 1.31        | 0.89       | 2.35*        | 1.70          | 0.01        |
| Ants           | 0.25    | 0.62   | 0.48         | 0.39        | 0.58       | 1.57         |               |             |
| Herbivores     | 0.47    | 0.36   | 1.65         | 1.10        | 0.85       | 1.47         | 0.50          | 0.31        |
| Evenness       |         |        |              |             |            |              |               |             |
| Predators      | 0.64    | 0.54   | 2.38*        | 0.22        | 1.00       | 2.25*        |               |             |
| Ants           | 0.39    | 1.06   | 0.08         | 0.43        | 0.65       | 1.64         |               |             |
| Herbivores     | 0.73    | 0.08   | 2.42*        | 1.16        | 0.58       | 1.16         |               |             |
| Abundance      |         |        |              |             |            |              |               |             |
| Predators      | 0.26    | 1.30   | 3.29***      | 3.73***     | 2.83**     | 4.90         |               |             |
| Ants           | 0.10    | 0.36   | 1.08         | 0.47        | 0.15       | 0.43         |               |             |
| Herbivores     | 0.26    | 0.54   | 2.10*        | 2.35*       | 0.28       | 1.00         | 0.29          |             |

Bold values represent significance (p < 0.05)
The value represents the z value, R² value represents the effect size of the model by determining how well the variables explain the model variance.

*p < 0.05, ** p < 0.01, *** p < 0.001
were significantly higher in mixed crops compared to mono crops during the long rains and significantly lower during the short rains (Supplementary materials 4). Predator abundance was significantly higher in indigenous hedges compared to exotic hedges during the short rains (Supplementary material 4).

Predator assemblage composition only responded to the interaction of farm type and maize cover for all seasons, while it responded to the cropping system during the long rains and the interaction between percentage maize and farm type, as well as the interaction between farm type and cropping system (Table 2, Fig. 5, Supplementary material 5). The percentage maize cover in the surrounding landscape was a significant driver of ant assemblage composition for both seasons combined and separately, while ant composition during the long rains showed an interaction between percentage maize and farm type, as well as the interaction between farm type and cropping system (Table 2, Fig. 5). Herbivore composition changed due to maize cover for both seasons combines and for the short

**Fig. 4** Significant response of abundance to the environmental variables (Table 1). Predator abundance in response to percentage maize (a); farm type (traditional (Trad) versus conventional (Conv)) (b); and the interaction between farm type (conventional = clear, traditional = black) and cropping system (monoculture of maize (mono) vs a mixed cropping system (mixed)) (c); Ant abundance in response to maize cover per farming system (black = conventional farming, grey dots and dashed line = traditional farming system) (d); herbivore abundance vs maize cover (e); and farming system (f)
rains, while hedge volume and type was also important during the short rains (Table 2, Fig. 5).

Discussion

Small scale traditional farms here had a much higher number of species, evenness and higher abundance than conventional farms. This is in line with most literature that compares industrialised farming to lower impact farming (Pimentel et al. 2005; Gaigher and Samways 2010). In fact, in this system the traditional farming is particularly low impact as it utilises few chemicals (primarily due to the prohibitively high cost of pesticides). These crops are grown for the farmer’s family and the local community only. Conventional farmers in this system have mechanised the ploughing and use many different pesticides. Also, conventional farms tend to be larger than traditional farms and part of this response may be due to reduced edge effect in the larger conventional farms (Botha et al. 2015). This creates a high contrast between the two farming systems and we can see that in the arthropod communities. It appears that traditional farming also reduces dominance amongst arthropod predators by broadening niches for multiple predatory species to co-exist (Bazzaz 1975; Schmidt et al. 2005).

A surprising result was the small difference between monoculture and intercropping, as across both seasons there was only a difference in predator evenness. During the long rains there was higher richness and abundance in the intercropped fields, in contrast to higher abundance in monoculture maize during the short rains. Intercropping has been well established as a sustainable and environmentally friendly farming method as it reduces the need for fertilizers and pesticides (Hassanali et al. 2008). Pests have been suppressed within maize fields of Kenya through intercropping, which creates more niche space through additional food and refuge resources which support a higher diversity and abundance of predators in the actual maize fields (Hassanali et al. 2008). The seasonal difference recorded here may be due to too little time for the arthropod assemblage to establish during the short rains or due to the farming systems having such a strong effect that these other factors are getting suppressed in the models, although this was accounted for in the study design. Interestingly, when the cropping system and farming type interacted, it was always the conventional farms that benefitted from intercropping. This is likely due to organic fields already having high levels of biodiversity and getting little additional advantage from intercropping (Galloway et al. 2021). This is similar to the intermediate landscape complexity hypothesis where the greatest benefits for agroecological schemes are in intermediate complex landscapes (Tscharntke et al. 2012). A further alternative is that this assemblage is influenced by spillover from neighbouring vegetation. This is more important than the infield condition, provided that it is not too hostile, such as those found on conventional farms (Tscharntke et al. 2005).

Table 2 Results of a manyglm comparing the response of environmental predictors to the composition of predator and herbivore assemblages

| Predictor     | Residual df | Both seasons | Long rains | Short rains |
|---------------|-------------|--------------|------------|-------------|
| Predators     |             |              |            |             |
| R²            | 0.37        | 0.40         | 0.40       |             |
| %Maize        | 14          | 6.78         | 5.96       | 4.53        |
| Farm type     | 13          | 4.27         | 3.34       | 2.82        |
| Cropping system | 12      | 3.83         | **6.04**   | 3.06        |
| Hedge volume  | 11          | 6.29         | 4.54       | 3.95        |
| Hedge type    | 10          | 3.92         | 3.21       | 2.39        |
| %Maize × farm | 9           | **5.52**     | 4.56       | **3.45**    |
| Farm × cropping | 8       | 0.76         | 1.88       | **3.26**    |
| Ants          |             |              |            |             |
| R²            | 0.36        | 0.40         | 0.35       |             |
| %Maize        | 14          | **10.67**    | **8.37**   | **8.20**    |
| Farm type     | 13          | 6.00         | 5.46       | 5.06        |
| Cropping system | 12      | 7.53         | 7.50       | 5.06        |
| Hedge volume  | 11          | 7.11         | 7.73       | 6.93        |
| Hedge type    | 10          | 7.29         | 6.07       | 5.80        |
| %Maize × farm | 9           | 5.88         | **7.18**   | 2.69        |
| Farm × cropping | 8       | 4.77         | **4.95**   | 1.93        |
| Herbivore     |             |              |            |             |
| R²            | 0.38        | 0.36         | 0.44       |             |
| %Maize        | 14          | **7.56**     | 6.23       | **5.18**    |
| Farm type     | 13          | 5.13         | 4.81       | 2.80        |
| Cropping system | 12      | 4.88         | 4.51       | 2.77        |
| Hedge volume  | 11          | 6.46         | 5.29       | **4.35**    |
| Hedge type    | 10          | 5.63         | 5.07       | **3.70**    |
| %Maize × farm | 9           | 3.54         | 2.99       | 2.26        |
| Farm × cropping | 8       | 3.50         | 3.17       | 0.73        |

Bold values represent significance (p < 0.05)

These result were calculated assuming correlated response via ridge regularization. Wald (figures in the table) and p-value calculated using 999 resampling iterations via probability integral transform residual bootstrapping

*p < 0.05, **p < 0.01, ***p < 0.001
Hedgerows had a positive impact on both predator species richness and evenness. The fact that they have a positive influence on arthropod diversity underscores the fact that heterogeneity is a keystone structural driver of predator assemblage composition and assemblage at the spatial and functional scales (Tews et al. 2004; Gaigher et al. 2016). There was only one response for type of hedge sampled (either alien or native vegetation), and that was predator abundance during the short rains, which preferred the exotic vegetation. This is likely due to the exotic vegetation being denser than the native vegetation and suggests that any additional vegetation promotes biodiversity on these landscapes. This fine scale landscape heterogeneity is critical for maintaining biodiversity in agricultural areas and is particularly important for maintaining beta diversity at local scales (van Schalkwyk et al. 2020).

In contrast, percent maize cover, which here had a positive overall influence on arthropod diversity in general suggesting that many species caught here in the maize fields are coming from other maize fields. There was an interaction with percentage maize cover and the farming system, with positive species richness and abundances more associated with conventional farming than traditional farms. This high species fidelity with maize fields suggests that at least some species captured here are maize species, which are strongly associated with the maize fields (van Schalkwyk et al. 2020). This also suggests that there is a high spillover between farms and maize fields, especially between conventional farms and this is likely due the high concentrations of these maize associated species on these farms within the general wider landscape. These crop species often play an important role in ecosystem services and a high diversity and abundance is important for these services especially in Kenyan maize fields (Midega et al. 2014; Otieno et al. 2019a).

Here predators were much more species rich and abundant than herbivores, and this is most likely due to predators occupying several trophic levels (Otieno et al. 2019a). Having more predators in farming systems is a major asset.

**Fig. 5** Latent biplots showing the similarity of sites (black = traditional, grey = conventional farms; circle = intercropping, square = monocropping) in response to ant, predator and herbivore assemblages. See supplementary material 5 to see equivalent residual biplots.
to farmers and this is likely to promote better top-down herbivore suppression (Otieno et al. 2019a). Ants were the most abundant taxa across all the farms studied, contributing nearly half of all arthropods seen in this study. Not only were they abundant, they were also represented by the largest number of species in all farms, making them useful for monitoring landscape-level trends in impacts of various agronomic management systems (as suggested by Anderson et al. 2004; Underwood and Fisher 2006). Ants have a gregarious nature and are able to exploit many prey items (Landis 2000), they are also responsible for protecting sap-feeding bugs such as mealybugs (Pseudococcidae: Hemiptera), from predatory attacks (Buckley 1991; Young et al. 1997). The three next most abundant arthropod families were all herbivores: Acrididae (grasshoppers), Curculionidae (weevils) and Gryllidae (crickets). However, although grasshoppers appeared to occur in maize-fields throughout the maize growth period, only a few of the species encountered constituted actual maize pests and in this study no locusts were encountered, which is the most destructive form of grasshoppers (Van-Huis et al. 2006).

Conclusion

This study demonstrates the value of small-scale traditional farming systems in maintaining in field diversity in farmlands. This has impact on arthropod diversity at the local scale, as well as potentially provisioning ecosystem services such as pest control and soil fertility (Phalan et al. 2011), while also having value at regional scales as they reduce isolation of remnant patches (Fahrig 2017). Multiple landscape elements assisted with increasing the diversity of these fields, particularly the percentage maize cover of the farm. Hedgerows most likely encouraged ubiquitous species and those associated with natural areas within the farmlands, but importantly they encouraged the predator assemblage. These practices are likely to achieve the best results if applied in conjunction rather than in isolation, as they are functionally complimentary in driving overall arthropod spatio-temporal community structures, dispersal and trophic interactions (Rusch et al. 2010). Conventional farms can improve biodiversity through the use of hedgerows and intercrops, although the best biodiversity management option is small traditional farms with hedgerows stands the best chance of ensuring resilience of the maize-fields and the promotion of biodiversity (Thies et al. 2003; Rusch et al. 2010; Samways et al. 2020).

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Author contributions All authors contributed to the study conception and design. Material preparation and data collection was conducted by JSP and analysis were performed by JSP. The first draft of the manuscript was written by NEO and all authors commented on preliminary versions of the manuscript. All authors read and approved the final manuscript.

Data availability The datasets generated during and analysed during the current study are available in the figshare repository, https://doi.org/10.6084/m9.figshare.12345788.

Declarations

Conflict of interest The authors declare that they have no conflicts of interest, and that there are no authorship disputes, contributions having been attributed appropriately with agreement of all co-authors.

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