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EFFECTS OF RESIDUE MANAGEMENT ON ARTHROPODS POPULATIONS UNDER CONSERVATION AGRICULTURE

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ABSTRACT

Maize (*Zea mays L.)* production in South Africa by smallholder farmers is primarily hampered by several factors, including institutional constraints, soil degradation, low input production, and insect pest attacks. Conservation agriculture (CA) is perceived as an approach that can help arrest or reverse the processes of soil degradation, improve soil fertility, pest management, and promote water conservation. However, results on the role of CA in pest management are contradictory. They show spatial and temporal variations due to the agroecosystem's complex interactions among biotic and abiotic components. This study employed the approach of the component omission to investigate the probable effects of crop residue management on insect pest populations in a maize-based cropping system. Field experiments were carried out at ongoing CA trials at the University of Fort Hare farm (UFH) (32° 47' S and 27° 50' E) and Pandulwazi High School (32° 39' S and 26° 55' E). The trial was set up in a split-split plot design with 16 treatments and 3 replicates. Main plots were allocated to two tillage levels, which were split into four different crop rotation levels as sub-plot treatments. The sub-sub plots were allocated to two residue management levels. For conventional tillage study, two levels of crop rotation and residue management were considered as the different CA adoption levels by smallholder farmers. The results revealed that crop rotation and residue management influence arthropod abundances, diversity, richness, and evenness, which can be used to predict or monitor pest outbreaks. However, the synergistic influence of environmental/climatic regimes cannot be separated from the individual agronomic practices. Furthermore, pest indices cannot be independently used to predict insect pest infestation and possible outbreaks; instead, they are dependent. Hence, they are site and time specific.

Key words: Conservation agriculture, pest management, residue management, smallholder farmers

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INTRODUCTION

Maize production in South Africa's Eastern Cape Province is generally low due to unfavorable conditions, pest attacks, and poor institutional and market structures [1, 2, 3]. The typical smallholder (subsistence) farmer’s maize production consists typically of traditional practices comprising rainfed, synergistic cultural pest management, and low input production approaches [4, 5]. The current South African government's thrust of improving agricultural productivity comprises the dissemination and implementation of new technological advancements, such as the GM maize and conservation agriculture practices [6, 7, 8]. Ultimately, these strategies have allowed enhanced agricultural production systems to improve productivity and food security among the resource-poor smallholder farmers. Intensive agricultural systems, such as the GM maize technology, are characterized by high productivity, high inputs (thus, pesticides and fertilizers), and increased mechanization, resulting in more simplified cropping systems [8, 9].

Conservation agricultural (CA) practices involving soil surface residue retention, diversified crop rotations, and minimum tillage are being promoted to enhance soil quality, increase yield, arthropod diversity at habitats, and arrest soil degradation [2, 10, 11]. Conventional agricultural practices are, however, believed to have long-term sustainability (environmental consequences of causing soil degradation through intensified tillage), surface residue removal (burning and/or grazing), reduced habitat diversity, and increased soil erosion due to reduced water infiltration when soils are compacted [12, 13, 14].

Soil surface cover involving organic mulches and/or crop residues, improves soil fertility and enhances ground arthropod assemblage, which helps keep pests in check [15, 16]. However, the effect of residue retention on the soil surface is contradictory in that it can raise or reduce crop pests, which can be of economic importance [17, 18]. However, these CA practices of residue retention and reduced tillage influence arthropod assemblage abundance of generalist predators, which can outweigh herbivorous pests [18]. Hence, this study investigated the interactions within the arthropod community of a typical maize-based cropping system from two Eastern Cape ecotopes.

METHODS AND MATERIALS

Study sites and experimental design

Field experiments were carried out at ongoing CA trials at the University of Fort Hare farm (UFH) (32° 47' S and 27° 50' E) and Pandulwazi High School (32° 39' S

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and 26^o 55' E), which represent Alice Jozini and Pandulwazi Jozini ecotopes, respectively. The UFH site is at an altitude of 508 meters above sea level with a semi-arid climate and an average annual rainfall of about 575 mm. Pandulwazi is at an altitude of 750 meters above sea level with a sub-humid climate and receives an annual rainfall of 750 mm. Both sites have soils of the Oakleaf form [19].

The ongoing trial was laid in a split-split plot design with 16 treatments (2x4x2) and 3 replicates. Main plots were allocated to no-tillage (NT) and conventional tillage (CT). Subplots were four crop rotations; maize-fallow-maize (MFM), maize-fallow-soybean (MFS), maize-wheat-maize (MWM), and maize-wheat-soybean (MWS). Sub-sub plots were residue management at two levels: residue removal (R_-) and residue retention (R_+). The net plot sizes were similar at both sites measuring 3 × 4 m.

Agronomic practices

Experimental sites were initially established in December 2012 by plowing, disking, and harrowing to make a fine tilth for crop establishment. From 2012 summer to 2014, a medium season and prolific GM (BR) maize cultivar (BG 5785BR) was used for the trials. In the summer season of 2015, PAN 6616 was planted as recommended under dry land productions in the central EC [1]. Fertilizer was applied to the summer maize crop at a rate of 90 kg N, 45 kg P, and 60 kg ha^{-1} K in all plots. All the P, K, and a third of the N fertilizer was applied at planting as a compound (6.7% N; 10% P; 13.3% K + 0.5% Zn) and the rest (60 kg) as LAN at 6 weeks after planting (WAP) by banding. The field trial was maintained under rainfed production conditions. Main plot treatments were effected just before the planting of a rotational crop, and crop residue treatments were effected soon after harvesting each rotational crop. Rotational sequences grown for the whole period are shown in Table 1. Weeds were managed from time to time to maintain bare ground and mulch treatment plots free of weeds. For the GM maize, glyphosate was used to control weeds at a rate of 4ltrs/ha, and for PAN 6616 and wheat, basagran was used at a rate of 3ltrs/ha. For the mulch treatment plots, all maize stalks and wheat straw were retained in the field.

Measurements and procedures

Of the 48 treatments per site in the long term trial, 12 were selected for the research experiment for the purpose of the study. The ones considered were the full entry conventional tillage plots (CT), MFM and MWM rotations with retention or removal of the previous seasons' crop residues. The MWM/MFM tilled plots with either residue removal or retained were considered as the different adoption/or entry levels of CA by smallholder farmers. For this research, the MFM tilled plots with residue removed were considered to be as full smallholder conventional agriculture treatments.

To characterize the assemblage of surface arthropods, pitfall traps were employed (at a depth of 120 mm and 170mm diameter), using a mixture of water and kitchen detergent for easy drowning of the insects. Traps were buried so that the upper edge flushes with the soil surface to enable crawling insects to drop inside. Traps were left in the field (day and night) and sampling was done at weekly intervals. According to established keys, arthropods were preserved in 70% ethanol, counted, and identified to at least a genera level. Trapping was done for 18 instances during the growing season, firstly in the week before planting, a week after planting (after emergence), and at weekly intervals for the rest of the growing season. Two pitfall traps were placed in transect within each treatment net-plot area. Total activity densities per plot were determined by summing up the numbers of arthropods captured in each trap.

After crop emergence, plant stand and above-ground visual insect assessments were conducted to determine plant density and plant damage due to infestation, such as boring or chewing damage. The number of damaged plants with a particular insect was calculated per plot to have the percentage of infestation. Infestation sampling was done weekly during the growing period up to harvesting, and each sampling was treated separately from the subsequent ones. Plot border rows were excluded during the establishment of plant stands and above-ground assessments.

Data analysis

For each sample treatment, species composition data derived from pitfall trap counts were analyzed to determine the insect species diversity, species richness, and species evenness. Species diversity was calculated as:

$H' = -\sum(Pi.\ln Pi)$
where: Pi = proportional abundance of the i^{th} species
$\ln Pi$= natural logarithm of Pi [20]

Species richness (R) was calculated as the total number of species present in the habitat [21]. Species evenness, the distribution of species abundance among species was calculated using the Simpson's Index as:

$D = 1-\{\sum n(n-1)/N(N-1)\}$ [21, 22]
where, n = the total number of insects of a particular species
N = the total number of insects of all species

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The data of insect abundance, diversity, richness, evenness, and above-ground insect samples were analyzed using analysis of variance (ANOVA) procedure with the site, rotations, residue management, and their interaction as sources of variation (JMP Version 12, SAS Institute Inc.). Above-ground infestation for each insect species was also analyzed using JMP, and plot treatment means were used to plot graphs of the insect activity over the growing period. Treatment means were separated using the least significant difference (LSD) test (P ≤ 0.05) when ANOVA showed a significant treatment effect.

RESULTS AND DISCUSSION

Pitfall traps

Species composition

An analysis of data from pitfall traps (totaling 432) from both sites (Pandulwazi and UFH) revealed that field crickets *(Gryllus sp.)* constituted the largest proportion (61%) of ground-dwelling arthropod species in the maize plots, followed by hoverflies (Allograpta) (24.1%) and bollworms (Helicoverpa sp) (7%). The representation of dragonflies, cutworms, and praying mantis, was 2.7%, 2.7%, and 2.2%, respectively (Table 2). The least observed species were Pterostichus sp., constituting 0.22% of the total pitfall catches.

The general trend of the combined species composition was largely recorded from residue retained treatment plots in both rotational sequences (MFM and MWM) than in residue removed plots (Figure 1). The trend showed that field crickets largely dominated the ground arthropod community while the remaining species collectively constituted about 40% of the total ground-dwelling arthropods in all of the treatment plots.

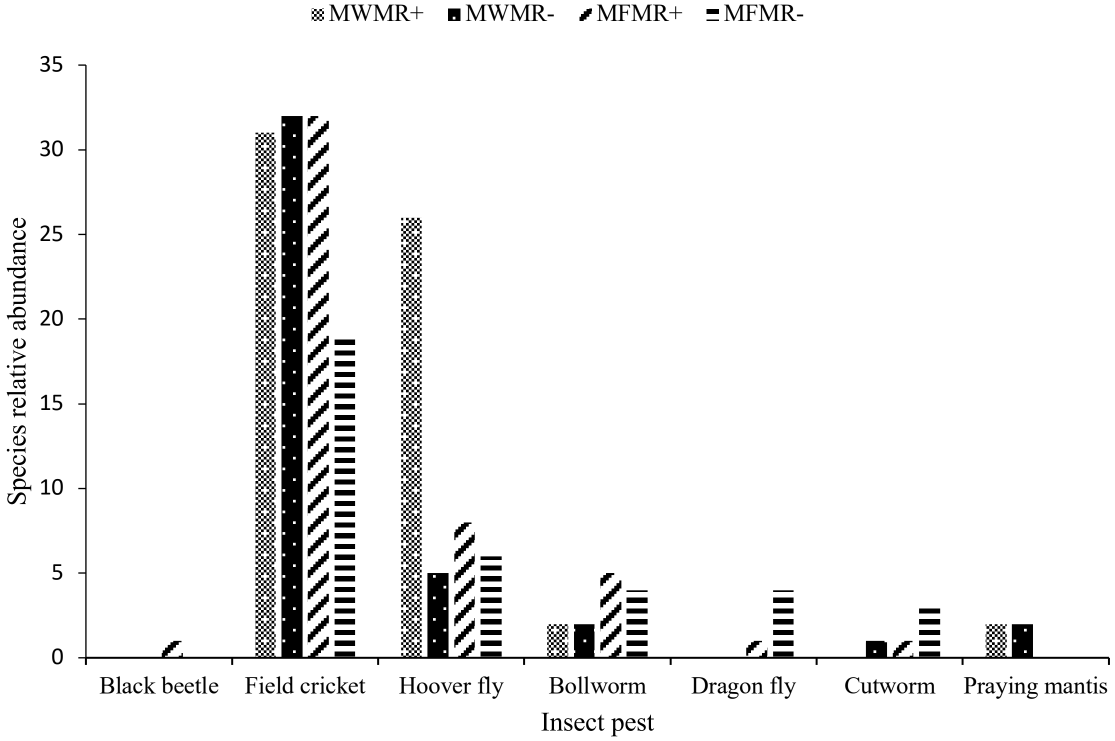

Figure 1: Species relative abundance from the two rotational sequences and residue management levels

However, the site combined relative abundance of the arthropods only significantly (P < 0.05) influenced the occurrence of dragonflies (P = 0.01) through the effect of rotations with MFM having more recordings than MWM (Table 3). The individual site species abundance patterns were significantly (P < 0.05) different in the occurrence of field crickets (P = 0.00), hoverflies (P = 0.04), bollworms (P = 0.03), and dragonflies (P = 0.02), mainly due to the difference in the location of the sites with Pandulwazi having more species than UFH (Table 3).

The general distribution of the individual species diversity indices between the two experimental sites reflected that Pandulwazi plots had higher indices than UFH plots. Plots from Pandulwazi were more diverse as compared to those from UFH as the majority of them had indices greater less than 1 (Figure 2). The more the diverse species index drifts from zero (or less than zero), the more diverse that habitat will be.

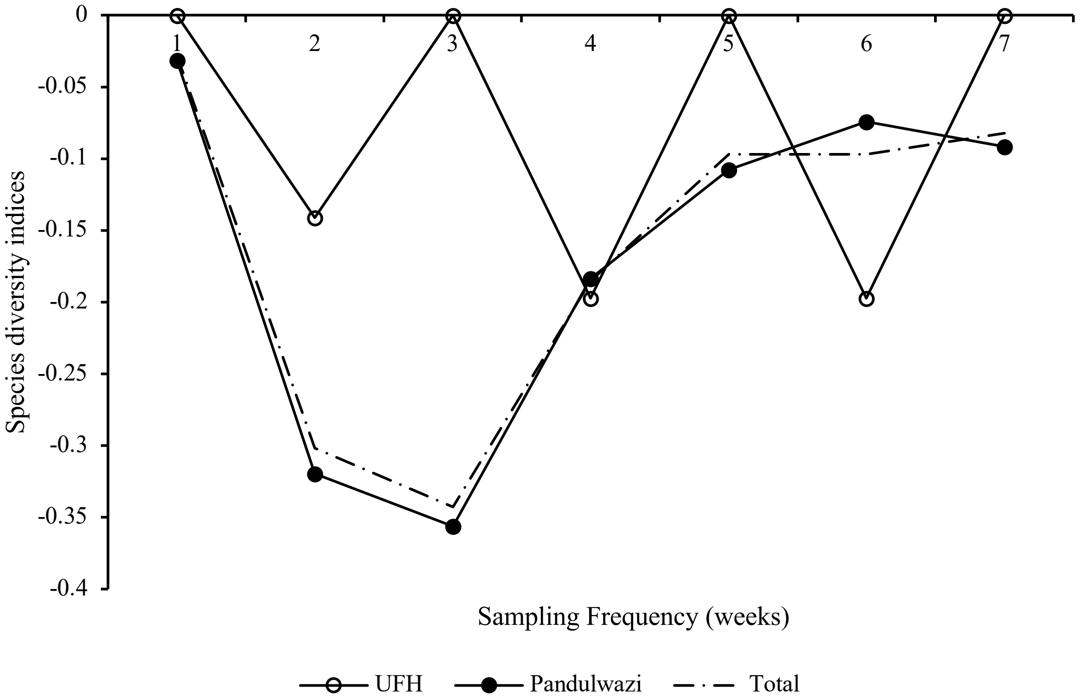

Figure 2: Individual species diversity indices between the two sites (x-axis is the sampling frequency, y-axis is diversity index)

The different arthropods diversity indices of observed species may be attributed to habitat disturbances and different experimental sites. The sampled plots resembled agroecosystems arising from intensive agricultural practices; though some had crop rotations and residues retained, their ultimate effects were traded off by continuous tillage operations [23]. Under these conditions, niche diversity declines, resulting in species inter-competition and adaptation to survive the ecological disturbances. Intensive tillage practices coupled with herbicide applications generally reduce/remove weeds, consequently reducing herbivore prey populations for ground-dwelling predacious arthropods [12]. The influence of site-specific environmental conditions was also evident that Pandulwazi had higher species relative abundances than UFH. Pandulwazi has semi-humid climatic conditions with richer vegetation and UFH, semi-arid conditions. These differences affect the resultant agroecosystem and arthropods within those ecosystems.

Plot sizes could have masked the effects of the treatments tested on species abundance and diversity. Plot sizes influence the population dynamics of target and non-target arthropods within that particular agroecosystem, which is based on the behavior of that particular species. Arthropods are highly mobile, with small plots, there was a high potential for movement between experimental treatments. Liu *et al.* [24] envisaged a plot size of 30m^2 to be sufficient to test treatment effects on maize bollworms. However, there is a strong correlation that arthropod populations within a specific agroecosystem will stabilize over time, as with the study sites [17].

Blocking and rotation effects

The overall plots of species diversity indices, richness, and evenness did not have any significant differences ($P > 0.05$) due to the effect of replications, rotations, and residue management treatments (Table 4). However, indices from Pandulwazi had higher values than the ones from the UFH farm. The first and third replication had the most species diversity, richness, and evenness compared with the second replication from both sites. There were no significant ($P > 0.05$) differences from rotational effects on the species diversity indices, evenness, and richness from both sites (Table 4). However, the MWM sequence had more species evenness and richness than MFM in Pandulwazi, whereas the latter had more species diversity indices than the former. The UFH farm MFM sequence had higher values of species diversity, richness and evenness than the MWM sequence.

While the long-term effects of crop rotations in this system were not examined, no significant differences were observed to influence species evenness between the two crop rotation treatments. However, the differences in arthropod densities are comparable between the rotation treatments. The urge to allow natural pest control within agroecosystems, especially CA, is the driving force to promote crop rotations as a beneficial integrated pest management (IPM) tool [13]. The indices, which had no significant differences due to the rotations, can be attributed to the type of residues left in the field before planting of the next crop. The residues influence the agroecology in which the arthropods thrive; this will alter the species' balance before planting the next rotational crop [14, 25]. From the particular sampled plots, the crops included in the rotations belong to the same classification family. Hence, the principle of practicing ecologically diverse/viable rotations is not being met to fully benefit from the treatment of crop rotations. A comparison of the site index values reflects the part of climatic factors in enhancing rotation treatment effects.

Effect of residue management

No significant ($P > 0.05$) differences were observed in the treatment influence on species diversity indices, species evenness, and richness from both sites. At Pandulwazi, the plots with residues retained were more diverse than those where residues were removed, having a percentage mean difference of 13.4%. In contrast, plots at UFH with residue removal had more species diversity and richness than the ones where residues were retained (Table 4). Interaction effects of crop rotations and residue management were insignificant (P > 0.05) concerning species diversity, richness, and evenness from both sites.

The residue treatment did not significantly influence the arthropod assemblage across the maize plots. High arthropod diversity in residue retained systems can be synergistically harnessed, coupled with crop rotations, to fully benefit from natural enemy activity within a diverse agroecosystem. Residue retention in the field helps in enhancing/maintaining a predator assemblage, which will keep pests in check in the early developmental stages of crop growth or establishment [14, 26]. This will enhance crop establishment and promote crop stand in the field when they escape early season pest attack. The higher evenness of the arthropod species in the residue removed plots showed that the relationship of a diverse agroecosystem to species abundance does not always conform to a constant. It also shows some measurable level of predators in fields without residue cover.

Seasonal activity

Ground arthropod activity was recorded from just before planting up to the mid-season of the maize growing period. Species abundances started at low levels at both sites, but rapidly increased with the onset of rains early in the growing season (Figure 3). The sharp drop in species after the third sampling date can be attributed to the mid-season dry spell experienced during the 2015/16 summer season at both sites. The gradual increase in species abundance after the sixth sampling date can be due to the improvement of the rains, especially at the Pandulwazi site than at UFH.

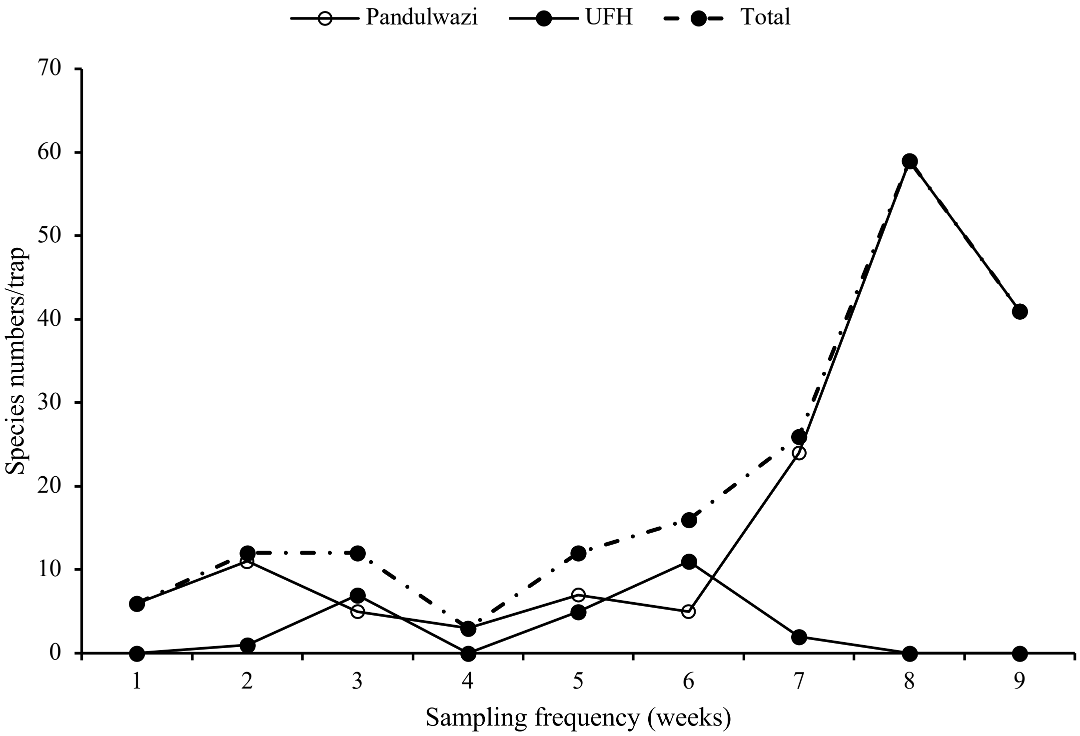

Figure 3: Seasonal abundance patterns of the total species from the experimental plots

The low abundance values at UFH, compared to those at Pandulwazi, are mainly due to persistent drought conditions experienced during the season. This is mainly due to the different environmental conditions between the two sites (Figure 4).

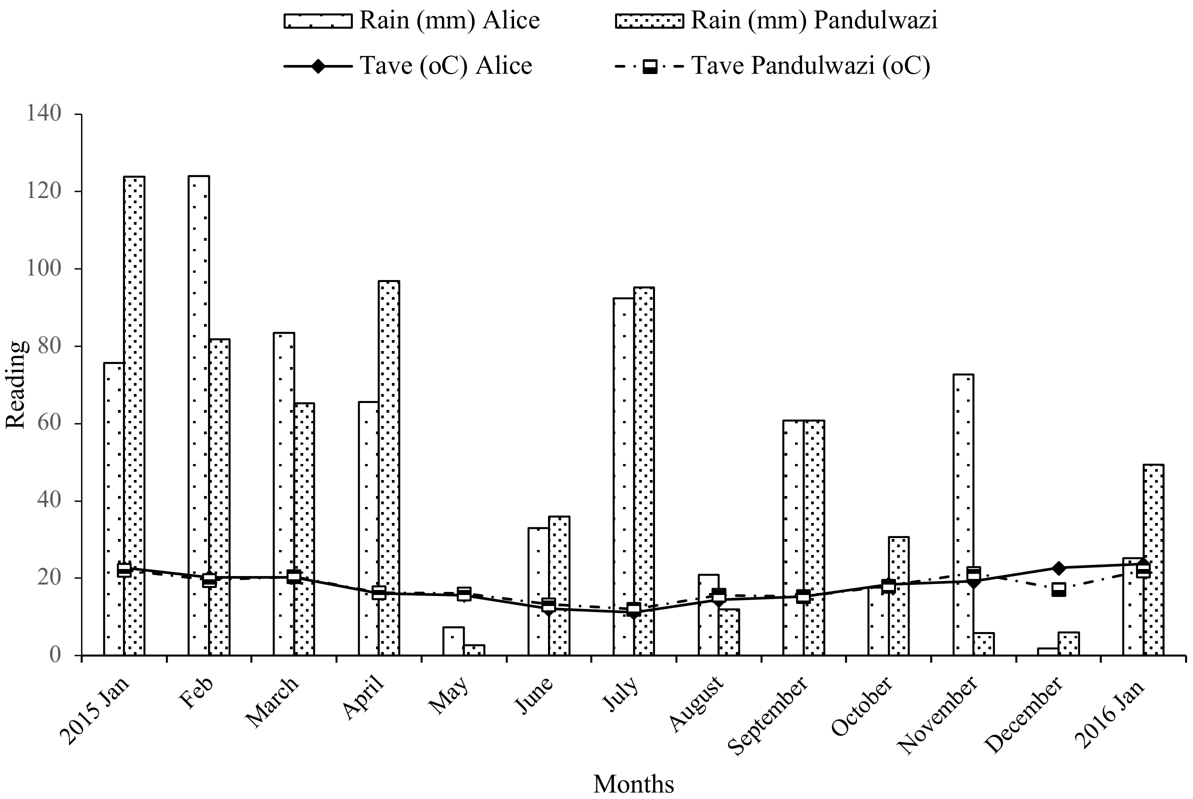

Figure 4: Total rainfall (mm) and average temperature (°C) for the two sites

There were no significant differences (P > 0.05) due to the treatment effect of crop rotations throughout the maize growing season (Table 5). However, there were significant differences (P < 0.05) due to the effects of locality differences, residue management, and the interaction between rotations and residue management. Species diversity was significantly (P < 0.05) influenced by the difference in site locations on date 2 (p = 0.02), date 7(p = 0.00), date 8 (p = 0.00) and date 9 (p = 0.00). Pandulwazi had higher species diversity indices than UFH in all instances (Table 5). The effect of residue management treatments significantly (P < 0.05) influenced species diversity on the eighth sampling date (p = 0.02). The treatments with residue retained had more species diversity indices than the plots where residues were removed. The treatment interaction effects significantly (P < 0.05) influenced species diversity on the ninth sampling date (p = 0.02). Treatment interactions of MWMR+ and MFMR- had higher species diversity indices more than the MWMR- and MFMR+ (Table 5).

The seasonal dynamics of the ground-dwelling arthropods from the sampled plots cannot solely depend on the treatment effects and habitat disturbances, but also on the climatic regime in humidity, temperature, day length, and field soil moisture [27]. Climatic weather elements' extremes influence selection pressure on the species, the available food reserves, adaptation to sharp changes, and the ultimate distribution of the competitors. Species populations started to peak approximately a week after planting, thus, with a corresponding increase in rains. The species abundances plummeted mid-season due to the dry-spell experienced. However, there were some observed arthropod activities during the dry period, signaling the presence of stress-tolerant arthropods. This can be beneficial to help keep pests at check, especially in intensive conventional agricultural systems, which are deemed to have typical conditions, as depicted in the experimental trial.

The above-ground insect pest infestation assessments

Visual assessments were conducted to determine seasonal insect pests' infestation cycles throughout the maize growing period. Sampling was targeted on the most economically important insect pests such as cutworms, stalk borers, bollworms, armyworms and aphids. The most recorded insects were nocturnal Lepidoptera (Noctuidae and Crambidae), followed by Acrididae (Orthoptera), Coloeptera and lastly Demeptera.

Treatment effects on insects infestations

Significant treatment effects ($P < 0.05$) on insect pest infestations were only observed under residue management ($p = 0.045$) on the percentage infestation by spotted stalk borer (Table 6). The effect of the seasonal changes had significant differences ($P < 0.05$) on the level of infestations by cutworms ($p = 0.001$), maize stalkborers ($p = 0.003$) and bollworms ($p = 0.04$). There were no significant differences on the interaction effects of crop rotations, residue management and season on insect infestations.

However, although there were no significant differences of the treatment effects on the infestation by cutworms, stalkborers and bollworms the treatment means exhibited different levels of activity across the insects. The r^2-value tests the correlation between the investigated variables. The closer the r^2-value it is to one (1), the strongest the relationship between the variables being tested. The r^2-values obtained from the experiment were in the range from moderate to high, signifiying positive correlation between the variables. Figure 5 shows spotted stalk borer infestation, which had significant differences due to residue management and seasonal changes. The treatment means had an r^2 value of 0.49 at α-level of 0.05. There was higher infestation in plots which had residues removed than the ones with residues retained from both rotation treatments.

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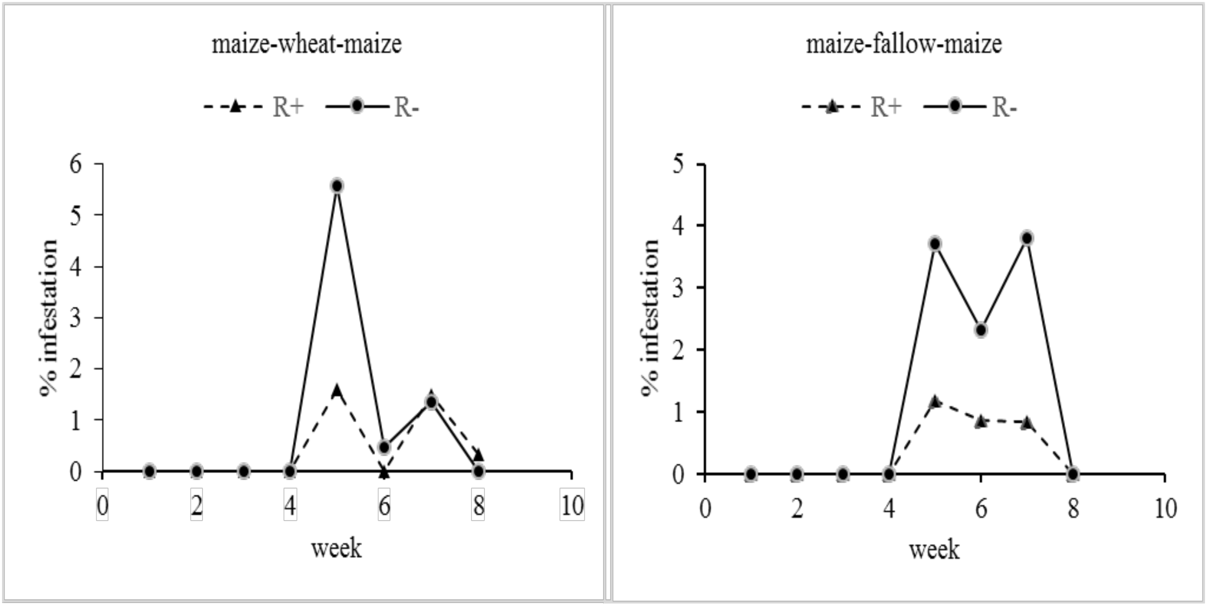

Figure 1: Seasonal infestation by spotted stalk borer

Infestation by cutworms was only significantly influenced by season climatic changes. There were higher levels of infestation early in the season which sharply declined mid-season (Figure 6). The treatment means had an r^2value of 0.65. There was relatively higher infestation by cutworms in residue retained plots as compared to those with residue removed.

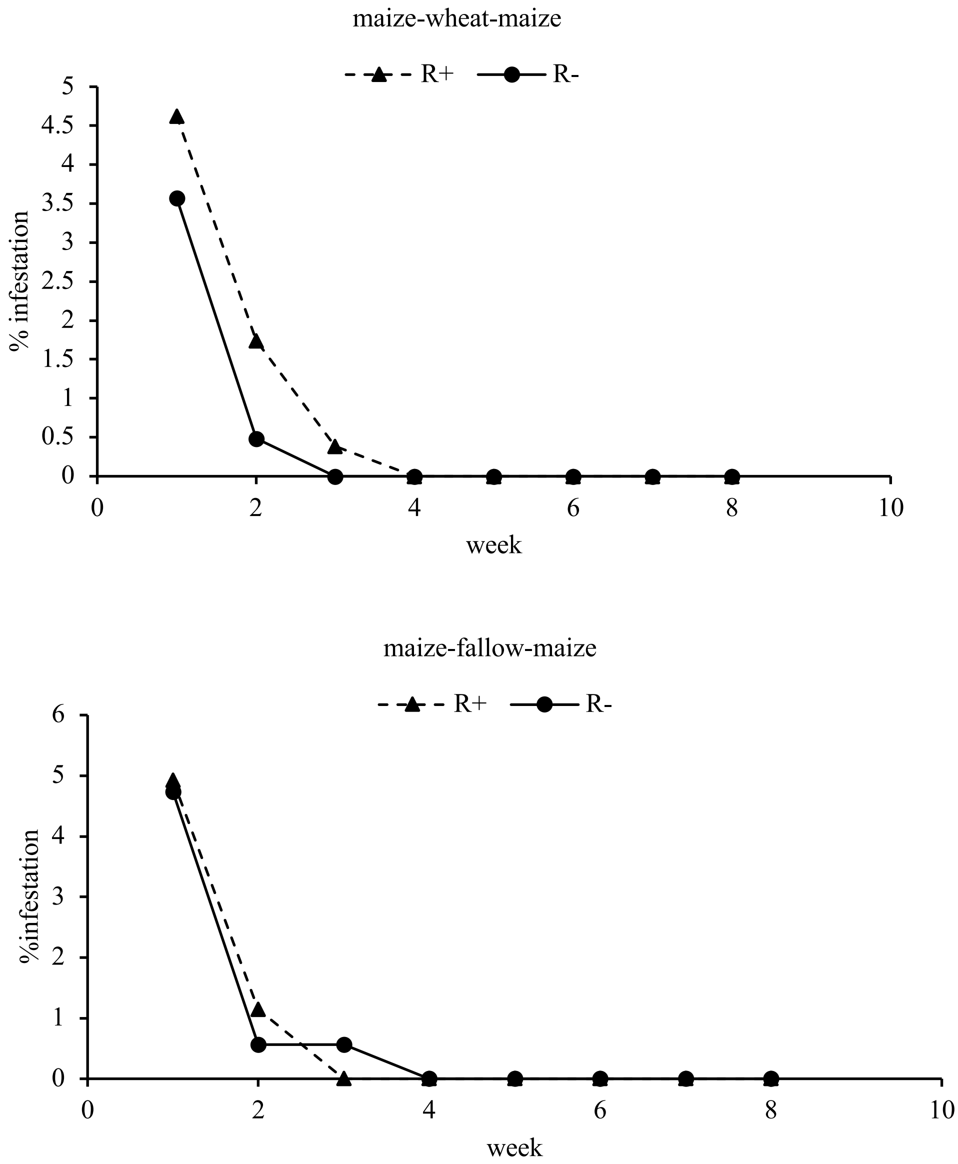

Figure 2: Seasonal infestation by cutworms

Infestation by maize stalk borers against the different treatments had an r^2 value of 0.37 and an F-value of 3.37 for the significant effect of seasonal change. Infestation by maize stalk borers was observed early in the season and it spanned throughout the growing season peaking mid-season. Relatively, infestation was higher in plots where residues were removed and MFM rotational treatments (Figure 7).

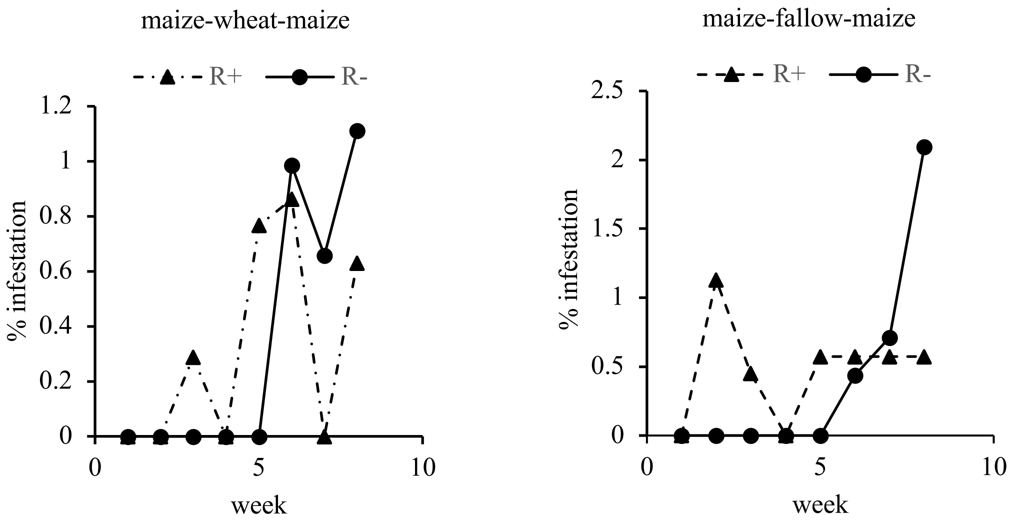

Figure 3: Seasonal infestation by maize stalk borer in maize plots

Bollworm activity was also influenced by changes in the season, infestation had an r^2 of 0.38, which was pronounced by double peaked levels from both rotational plots as well as residue management. Infestation levels were higher in residue retained plots than in residue removed (Figure 8). MWM treatments had an overall higher observed infestation level than the MFM rotation.

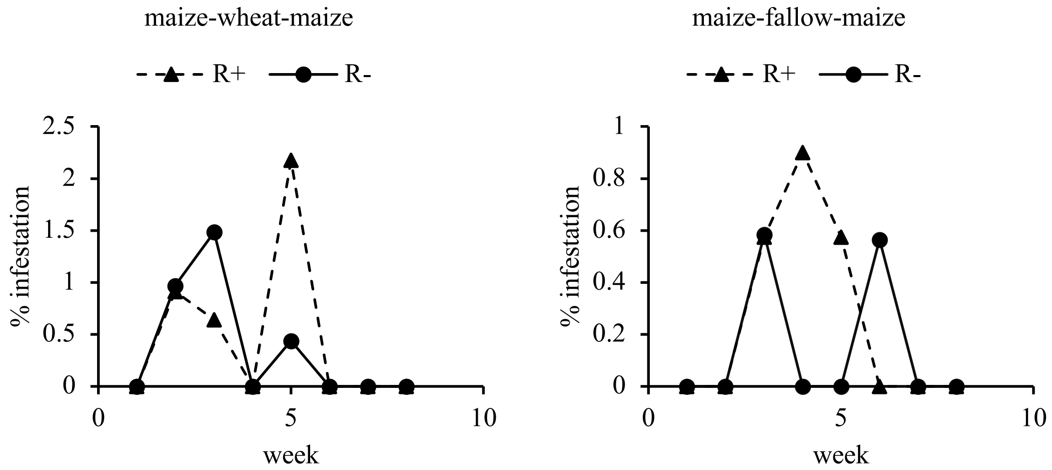

Figure 4: Seasonal infestation by bollworm in maize plots

Treatment effects were only observed to significantly influence infestation by spotted stalk borer through residue management in both rotational treatment plots. There were higher infestation levels in residue removed plots as compared to residue retained plots. This phenomenon may be attributed to the absence of natural species balance checkers resulting in high infestation levels in the plots where residues were removed. This scenario is similar to the one [12] observed in that tilled maize fields with residue retained had low predacious densities as compared to full CA plots. Full CA plots, which are similar to the examined tilled plots coupled with residue retention, are more species even which subsequently promote the proliferation of antagonists and predacious arthropods which play a vital role in agro-ecological stability. More stable agroecosystems keep pests in check and prevent possible outbreaks naturally, this is in agreement with Govaerts [28].

The effect of climatic regime on the relative abundances of the species was significantly expressed across all the treatments and the specific arthropods. The absence of significant rotation and residue management effects in majority of the plots is evidence that the seasonal climatic changes masked their effects. The study coincided with a lower than average rainfall season which had a severe mid-season dry spell. A comparison of the arthropods infestation trends shows a mid-season peak of spotted stalk borer and bollworms in both rotational and residue management plots. Maize stalk borer exhibited a contrasting trend due to the difference in the rotation treatment, with a mid-season peak in the MWM and residue management plots. In contrast, there was a sharp drop in maize stalk borer infestation in the MFM plots. This complex environmental influence phenomenon is consistent with Rendon [18].

CONCLUSION

Agronomic practices such as crop rotations and residue management have been shown to influence arthropod abundance, diversity, richness and evenness which can be used to predict or monitor pest outbreaks. However, the synergistic influence by environmental/ climatic elements regimes cannot be separated from the individual agronomic practices. The results have shown that abundance, diversity, richness or evenness indices cannot be independently used to predict insect infestation and possible outbreaks, but rather they are dependent hence, are site and time specific. Since these indices reflect how the species will behave within an agroecosystem, at times, results exhibit contrasting species activities to the norm due to complex interactions within the same habitat. In this one-season experiment, focus was on conventionally grown maize with either residue retained or removed under two rotations. In this regard, a long-term arthropod assessment from different tillage practices and under diverse crop rotations is recommended. This will allow certainty in linking a treatment variable to the ultimate response of the arthropods within that agroecosystem.

Table 1: Summary of rotational treatments

Crop rotation	Summer (2012/13) Season 1	Winter (2013) Season 2	Summer (2013/14) Season 3	Winter (2014) Season 4	Summer (2014/15) Season 5	Winter (2015) Season 6	Summer (2015/16) Season 7
MFM	Maize	Fallow	Maize	Fallow	Maize	Fallow	Maize
MFS	Maize	Fallow	Soybean	Fallow	Maize	Fallow	Soybean
MWM	Maize	Wheat	Maize	Wheat	Maize	Wheat	Maize
MWS	Maize	Wheat	Soybean	Wheat	Maize	Wheat	Soybean

Table 2: Relative abundance of the different species from both sites

Species name	Relative abundance (%)		
	Pandulwazi	UFH	Combined Sites
Black beetle *(Pterostichus sp.)*	0.62	0	0.53
Field cricket *(Gryllus sp)*	57.14	84.62	60.96
Hoverfly *(Allograpta sp)*	27.95	0	24.06
Bollworms *(Helicoverpa sp)*	6.83	7.69	6.95
Dragonfly *(Anisoptera sp)*	3.11	0	2.67
Cutworm *(Agrotis sp.)*	1.86	7.69	2.67
Praying Mantis *(Mantis sp.)*	2.48	0	2.14

Table 3: Treatment effects on individual species diversity indices

Treatment	Beetles	F.cricket	Hoverfly	Bollworm	Dragonfly	Cutworm	P.mantis
Site							
Pandulwazi	ns	*	*	*	*	ns	Ns
UFH	ns	*	*	*	*	ns	Ns
Rotation							
MFM	ns	ns	ns	ns	*	ns	Ns
MWM	ns	ns	ns	ns	*	ns	Ns
Residue Management							
Removed (R-	ns	ns	ns	ns	ns	ns	Ns
Retained(R+)	ns	ns	ns	ns	ns	ns	Ns
Rotation x Residue							
MFM, R-	ns	ns	ns	ns	ns	ns	Ns
MFM, R+	ns	ns	ns	ns	ns	ns	Ns
MWM, R-	ns	ns	ns	ns	ns	ns	Ns
MWM, R+	ns	ns	ns	ns	ns	ns	Ns

Table 4: Species characteristics (mean±s.e) as influenced by rotations and residue management

Treatment	Shannon's Diversity	Richness	Simpsons' Index	Shannon Diversity	Richness	Simpsons' Index
	Pandulwazi			UFH		
Rotation						
MFM	0.99±0.11a	11.8±2.92a	0.38±0.06a	0.22±0.09a	2.50±0.35a	0.56±0.23a
MWM	0.84±0.11a	15.0±2.92a	0.45±0.06a	0.09±0.09a	1.83±0.35a	0.42±0.23a
Residue Management						
Removed (R-	0.84±0.11a	10.2±2.92a	0.45±0.06a	0.32±0.09a	2.83±0.49a	0.47±0.23a
Retained(R+)	0.97±0.11a	16.7±2.92a	0.39±0.06a	0.00±0.09a	1.50±0.45a	0.50±0.23a
Rotation x Residue						
MFM, R-	0.98±0.15a	10.0±4.13a	0.37±0.09a	0.44±0.13a	2.67±0.70a	0.44±0.33a
MFM, R+	0.99±0.15a	13.7±4.13a	0.40±0.09a	0.00±0.13a	2.33±0.70a	0.67±0.33a
MWM, R-	0.70±0.15a	10.3±4.13a	0.54±0.09a	0.19±0.13a	3.00±0.70a	0.50±0.33a
MWM, R+	0.96±0.15a	19.7±4.13a	0.37±0.09a	0.00±0.13a	0.67±0.70a	0.33±0.33a

Table 5: Seasonal dynamics of the species diversity at Pandulwazi and UFH sites

Treatment	Date1	Date2	Date3	Date4	Date5	Date6	Date7	Date8	Date9
Site									
Pandulwazi	ns	*	ns	ns	ns	ns	*	*	*
UFH	ns	*	ns	ns	ns	ns	*	*	*
Rotation									
MFM	ns	ns	ns	ns	ns	ns	Ns	ns	Ns
MWM	ns	ns	ns	ns	ns	ns	Ns	ns	Ns
Residue Management									
Removed (R-	ns	ns	ns	ns	ns	ns	Ns	*	Ns
Retained(R+)	ns	ns	ns	ns	ns	ns	Ns	*	Ns
Rotation x Residue									
MFM, R-	ns	ns	ns	ns	ns	ns	Ns	ns	*
MFM, R+	ns	ns	ns	ns	ns	ns	Ns	ns	*
MWM, R-	ns	ns	ns	ns	ns	ns	Ns	ns	*
MWM, R+	ns	ns	ns	ns	ns	ns	Ns	ns	*

Table 6: Treatments effects on insect infestations

Treatment	Cutworm	Maize stalk borer	Bollworm	Spotted stalk borer
Crop rotation (R)	Ns	ns	Ns	Ns
Residue management (RM)	Ns	ns	Ns	*
Time (T)	*	*	*	*
R x RM	Ns	ns	Ns	Ns
R x T	Ns	ns	Ns	Ns
RM x T	Ns	ns	Ns	Ns
R x RM x T	Ns	ns	Ns	Ns

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