International Journal of Pest Management

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ttpm20

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To cite this article: David Ojuu, Samuel Kyamanywa & Thomas Odong Lapaka (2021): Influence of wetland borders on prevalence of fall armyworm and wasps in maize-soybean cropping system in Eastern Uganda, International Journal of Pest Management, DOI: 10.1080/09670874.2021.1918356

To link to this article: https://doi.org/10.1080/09670874.2021.1918356

Published online: 10 May 2021.

INTERNATIONAL JOURNAL OF PEST MANAGEMENT
https://doi.org/10.1080/09670874.2021.1918356

Influence of wetland borders on prevalence of fall armyworm and wasps in maize-soybean cropping system in Eastern Uganda

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ABSTRACT
The non-crop habitats within agro-ecosystems are important resources for ecological and biological insect pest management. Diversified cropping systems are known to influence pest populations, however, how neighboring habitats affect pest population dynamics is not clear. This study focused on understanding the influence of wetland borders on Fall Armyworm (FAW) and wasps prevalence in a maize-soybean intercrop system in Eastern Uganda. FAW and wasps population estimates were carried out in twelve farmers' fields stratified within 0–300 and 500–1100 meters from the wetland borderline. Data were collected biweekly from emergence until post flower growth of the crops. Results showed the prevalence of FAW was significantly higher on maize-soybean fields 500–1100 meters compared to those within 0 to 300 m from the wetland borders. While the prevalence of wasps was significantly higher in the crops at 82–219 meters from wetland borderline. It is concluded that wetland borders play a crucial role in negatively affecting crop pest populations while positively influencing natural enemy populations and these effects are influenced by distance of crop fields from the wetland border.

ARTICLE HISTORY
Received 16 December 2019
Accepted 12 April 2021

KEYWORDS
Wetland borders; fall armyworm; wasps; population estimates; maize-soybean intercrop

Introduction

In peasant dominated areas, the use of traditional farming practices has resulted in a varied, highly heterogeneous landscape possibly even more heterogeneous than would exist naturally (Rusch et al. 2013). Globally, there is a large scale simplification and alteration of agro-ecosystems and natural habitats with unprecedented decline in biodiversity (Tscharntke et al. 2016). The large scale simplification of agro-ecosystems have affected insect pest dynamics and thus greatly influenced farmers' decisions on use of chemical pesticides for pest management (Etile 2013). Moreover, chemical pesticides pose human and environment health risks and also are not sustainable for resource constrained farmers.

The existence of natural and semi-natural habitats within the simplified agro-ecosystems become inalienable resources, as they play a crucial function of influencing insect pests and natural enemies dynamics (Altieri 1994). Unfortunately with the accelerating habitat removal, the contribution of biocontrol agents from these habitats to pest suppression is diminishing and consequently agro-ecosystems are increasingly becoming vulnerable to pest outbreaks (Altieri et al. 2009).

The interface of natural, semi-natural habitats with cultivated patches can fundamentally be influenced by temporal and spatial scales and inadvertently affects species dynamics between and within these patches. However, the species capacity to survive and their effectiveness to perform within and across patches can greatly be influenced by species-specific life traits such as; ability to disperse, body size, sensitivity to disturbance, micro-habitat specialization and or trophic position (Rush et al. 2010).

The temporal dynamics specifically can affect spill-over effects of crop pests and natural enemies within the ecosystem. Cultivated patches often experience decline in resources due to continuous harvests, thus natural enemies emigrate to semi-natural and natural patches (Rand et al. 2006). Semi-natural and natural habitats thus play a role of serving as points for species development and survival during periods of low resources availability. They as well serve as starting points for colonization of crop fields at the start of a cropping season (Marshall 2004).

On spatial scale; distance between crop fields and non-crop habitats influences insect pests and natural enemy population dynamics and could have a bearing on the prevalence of some pests and diseases in crops (Al Hassan et al. 2013). Similarly, in the context of landscape complexity, a correlation between insect pest abundance and habitat patchiness could exist and thus influence pest prevalence at varying

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spatial scales. For example, Grilli and Bruno (2007) found that the abundance of corn hopper (*Delphacodes kuscheli)* increased with abundance and connectivity of its host patches and thus affect pest abundance as well as damage on crops.

However, at field level sustained pest regulation may depend on continued supply of natural enemies from the natural and semi-natural vegetation adjacent crop fields (Olson et al. 2006) and may also be influenced by their bidirectional movement in regards to resource needs (Tscharntke et al. 2007). Therefore, the source-sink and bidirectional movement patterns affect the spatial and temporal spill-over effects of natural enemies for effective pest population regulation at agro-ecosystems.

Agro-ecologies can be mosaics interspersed with hostile matrix (Vandermeer 1995) and can present different complexities that influence insect pests and natural enemies' dynamics in time and space (Macfadyen and Muller 2013). Their connectivity to non-crop habitats such as wetlands is crucial to enhancing biological pest management within such complex crop fields. However the effectiveness of wetland borders functioning to support biodiversity in crop fields can be affected by how large and proximate enough they are to agro-ecosystems.

Fall armyworm is a recent invasive pest reported in the African continent (Goergen et al. 2016) to devastate maize crop. The management of the new pest currently is through chemical pesticide sprays, although there are reports of effective biological agents against the pest (Meagher et al. 2016) which could be used to manage the pest in agro-ecosystems, however, to benefit from these bio-control agents; stable and diverse ecosystems are necessary to support beneficial organisms functioning in agro-ecologies.

Some studies have reported movement of beneficial insects from the wetland borders and high biological control observed at field edges adjoining wetland borders and at finer spatial scales (Hogg and Daane 2013; Pfister et al. 2015). Also it is reported that fall armyworm can be managed through abundance and diversity of parasitoids that are supported by stable non-crop or semi-natural habitats (Meager et al. 2016). However, it is not adequately reported how far the spatial effects of wetland borders on influencing fall armyworm and hymenoptera wasps dynamics in a diversified cropping system such as that of maize-soybean intercrop can extend. Therefore, this study was conducted to understand the spatial influence of wetland borders on population dynamics of fall armyworm and hymenoptera wasps in maize-soybean intercrop system at spatio-temporal scales.

Methods and materials

Area of study

The study was conducted in Iganga district (Eastern Uganda). The district lies in the Kyoga plains agro-ecology of Uganda, which is characterised by 9% of the landscape under wetland and 49% of wetland area being converted to production of maize, soybeans, rice and vegetables (DDP, 2015). The district is also the leading producer of maize in Uganda (Uganda Bureau of Statistics 2009), The study site was in Namalemba Sub-county, Namalemba parish in the Naigombwa wetland system, a tributary of the Mpologoma river of the Lake Kyoga basin (MWE, 2016). Naigombwa wetland is located at 00.72963°N, 033.58718°E and about 22 km from Iganga town along Iganga-Mbale road. Being the biggest wetland in the district, a lot of agricultural production is carried out around its catchment and thus provided a good opportunity for studying the influence of wetland borders on pest and natural enemies' activity in relation to field distance from the wetland borders.

Selection of fields for experiment

The study was conducted in twelve farmers' fields that were selected by use of stratified and snowball sampling techniques. The study fields were considered within a distance of 1100 meter from the wetland border and were grouped into two strata considering the distance from the wetland borders inland. Two strata of 0–300 meters and 500–1100 meters from the wetland borders each comprising of six fields established at varying distances were considered.

The exact distances of each crop field from the wetland borders were established by taking coordinate readings from the field center using Geographical Positioning System (GPS). Later the geographical distances between the fields and wetland borders were calculated using package geosphere in R statistical software (Hijmans et al. 2017). The function "distVincentyEllipsoid" which measures the shortest distance between two points, according to the "Vincenty (ellipsoid)" method was used.

Establishment of experiments

The selected farmers were given the same maize variety (Longe 5) and soybean variety (Maksoy 5 N). Considering a common practice of intercropping maize and soybeans in the study area, farmers were only guided by the researcher to plant and manage their intercropped fields using standard agronomic practices. The intercrop ratio of 2 rows of maize followed by 2 rows of soybean (2:2) was used for planting maize-soybeans; maize was planted at a spacing of 90 cm between rows and 50 cm between plants within a row with two plants per hill while soybean was planted at spacing of 50 cm between rows and 10 cm between plants within a row and one plant per hill was used. The planting pattern and spacing used was uniform across all the study field. To ensure validity of the study, farmers were advised to prepare and plant fields early so that timely planting could ensure effective plant growth when the pest populations were low and thus chemical sprays were discouraged in the study fields.

The study was conducted for two cropping seasons of 2017A and 2017B; experiment in season 2017A was conducted in the month of; March to June while the experiment in season 2017B was conducted in the months of August to November

Sampling of fall armyworm and hymenoptera wasps

The sampling of Fall armyworm commenced one week after emergence of maize and soybean crops, this was repeated at two weeks interval until the maize crop had fully completed tasseling. A quadrant measuring 2 meters by 2 meters, fabricated locally out of metallic frame was used to delineate the sampling area. Five quadrants were taken along the two diagonals of each crop field.

In each quadrant containing about 17 maize plants, the total number of plants showing signs of fall armyworm damage was counted to determine incidence of damage as a percentage (%) of the overall sample. The percentage of damage was determined using the formula;

$$\text{Incidence of damage} = \frac{\text{Number of damaged plants}}{\text{Total number of plants sampled}} \times 100$$

To determine severity of fall armyworm damage, Ten (10) maize plants out of 17 plants in each quadrant were selected at random and scored on a scale of 0–9; where, 0 = No visual leaf injury, 1 = pinhole damage on a few leaves, 2 = small amount of shot – hole damage on few leaves, 3 = shot- hole damage on several leaves, 4 = shot-hole damage and lesions on a few leaves, 5 = lesions on several leaves, 6 = large lesions on several leaves, 7 = large lesions and portions eaten away on a few leaves, 8 = large lesions and large portions eaten on several leaves, and 9 = Total foliage and whorl leaf damage (Wiseman et al. 1966).

Destructive sampling was also done every two weeks by taking five plants with severe damage symptoms in each field. The selected plants were dissected to extract the larvae. Visual larval identification and counting was done in the field and clear distinction of fall armyworm larvae from non-fall armyworm was done based on morphological features of the larvae.

Sampling of hymenoptera wasps

Sampling for relative abundance of hymenoptera wasps was done in both wetland vegetation and crop fields through sweep net and water traps (Yellow and white water traps). Sampling was carried out at two weeks intervals (Sonja et al. 2015). In the wetland border points, diagonal movement pattern within 10 meter width of sampling transect was done and five sweeps in a given diagonal were considered to constitute one sample. Similarly for crop field sampling, sweep netting was done on crop canopy and diagonal movement pattern was adopted. Five sweeps constituted a sample and a total of four samples were taken in each field at every sampling time.

A total of twelve water traps at a spacing of 20 meters were installed in wetland border points, and six traps installed in each crop field. The traps were filled with 200 millimetres of water and 01 mls of 40% Formalin as preservative was added. The trapped insects were collected every three days, put in glass vials containing 96% ethanol. The identification and counting of the collected wasps were carried out in a laboratory. The trapping was carried out until the maize and soybeans had completed tasseling and podding respectively.

Data analysis

Data collected from the study were subjected to analysis of variance using Genstat software. Significant means were separated using Fisher's protected LSD at 5%, correlation and regression analysis was also done for relationships between pest and natural enemy (wasp) prevalence with distance from the wetland borderline. Data for every study season were analysed separately due to differences in seasonal conditions that could also affect pest prevalence and natural enemy abundance.

Results

Fall armyworm incidence

There was variability in fall armyworm prevalence across the two seasons of study, overall, higher incidences of fall armyworm were recorded in season 2017A (62%) compared to 2017B (35.7%). In both seasons, fall armyworm incidence increased with

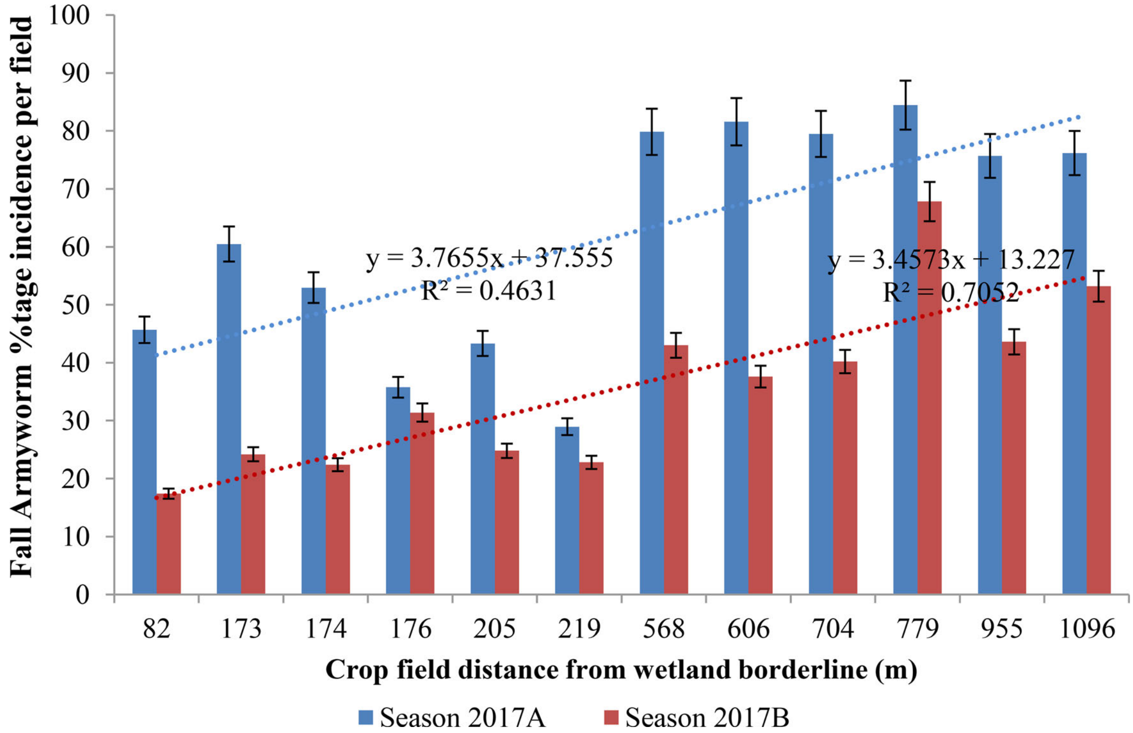

Figure 1. Influence of field distance from wetland borderline on Fall Armyworm incidence expressed as a percentage of maize plants showing injury signs averaged over the maize growth.

distances from the wetland borderline (Figure 1). Crop fields closer (82 – 219 meters) to the wetland borderline registered significantly ($P < 0.001$) lower fall armyworm incidence compared to fields further (568–1096 meters) from wetland borderline in both seasons. In 2017A, fields closer to wetland borderline on average, the percentage of damaged plants varied between 29 to 60%, while in crop fields 568–1096 meters from wetland borders, the proportion of damaged plants ranged between 76 to 84%. Similarly in 2017B, crop fields nearer wetland borderline (82–219 meters) registered fall armyworm incidence (%) between 17% and 31% compared to 43% and 68% for fields (568–1096 meters) far from the wetland borderline.

Furthermore, correlation analysis showed that there was positive correlation between crop field distances and fall armyworm incidences ($R = 0.681$, $P = 0.0019$.) in season 2017A and ($R = 0.840$, $P = 0.0005$) for 2017B showing a linear relationship between distance from wetland borderline and incidence of fall armyworm. The linear relationship was however, stronger in 2017B ($R^2 = 0.7052$) compared to 2017A ($R^2 = 0.4631$) (Figure 1).

Fall armyworm damage severity

Results showed that crop distance from the wetland borderline in both seasons 2017A and 2017B significantly ($P < 0.001$) affected fall armyworm damage. In season 2017A crop fields further (568–1096 meters) from the wetland borders, on average registered, high severity ranging 5.1 and 6.7 while closer crop fields to wetland boundaries (82–219 meters) registered low damage scores ranging 3.3 to 4.4. Similarly in 2017B, further crop fields (568–1096 meters from wetland borders) registered high severity ranging on average 2.9 to 5.0 while crop fields at distances; 82–219 meters from wetland borders registered FAW damage ranging 2.3 to 3.2 (Figure 2).

Similarly, correlation and regression analyses showed positive relationship between crop field distance and fall armyworm damage severity in season 2017A ($R = 0.718$, $P = 0.0086$) and season 2017B (0.773, $P = 0.0032$) indicating a linear relationship and strong linear relationship was observed in 2017B ($R^2 = 0.6025$) than 2017A ($R^2 = 0.4679$) (Figure 2)

Fall armyworm larval densities

Significantly ($P < 0.001$) high fall armyworm larval densities across the two seasons, 2017A and 2017B, were recorded in the crop fields established furthest 568–1096 meters from the wetland borderline while closer fields (82–219 meters) to the wetland borders had lower larval densities. In 2017A, on average per plant, high larval densities, ranging 9.0 to 14.6, were recorded in crop fields at distance range of 568–1096 meters away from the wetland borders, while plants in closer fields (82–219 meters) to the wetland borders had, comparably, low larval densities between 5.6 to 10.8. Similarly in 2017B, larval

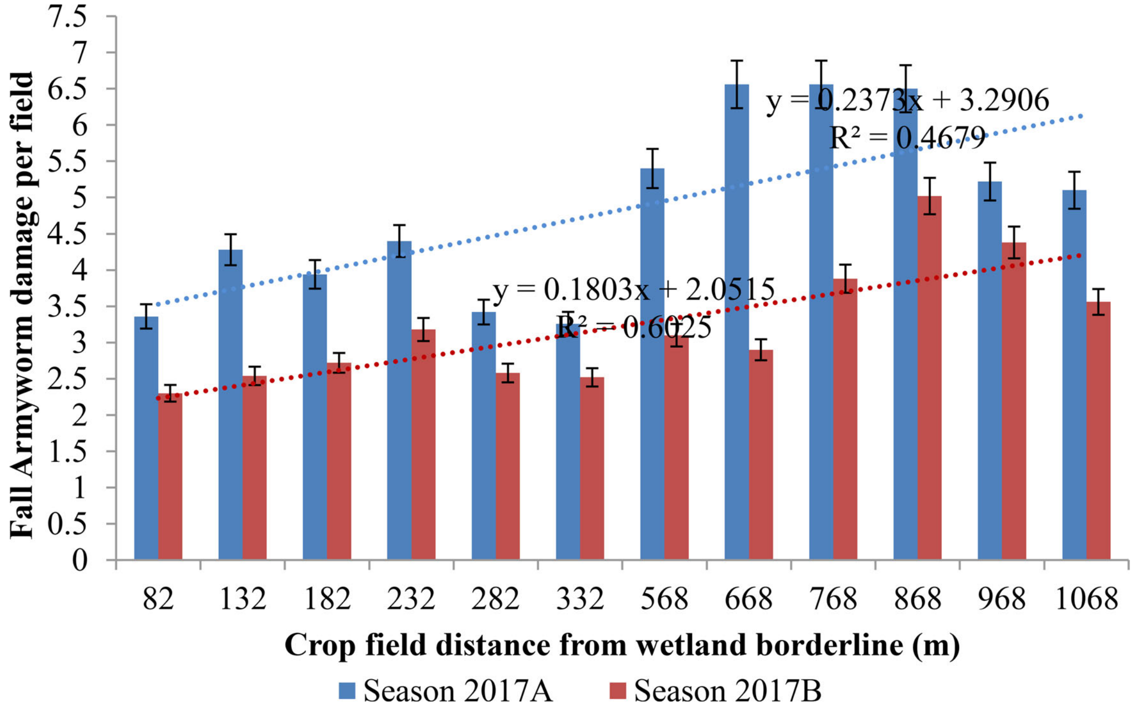

Figure 2. Effect of field distance from wetland border line on fall armyworm damage severity on maize.

Table 1. Effect of crop field distance from the wetland borders on fall armyworm larval densities.

Season 2017A			Season 2017B		
Distance strata	Field distances (m) from wetland borderline	Fall Armyworm larval densities/ 50plants (Means ± SEM)	Distance strata	Field distances (m) from wetland borderline	Fall Armyworm larval densities/ 50plants (Means ± SEM)
D1	82	9.8 ± 2.4	D1	82	5.4 ± 0.7
	173	7.2 ± 1.5		173	7.4 ± 1.6
	174	10.8 ± 2.7		174	7 ± 0.5
	176	8.8 ± 2.0		176	6.4 ± 2.3
	205	6.6 ± 1.9		205	5.6 ± 1.1
	219	5.6 ± 1.0		219	6.2 ± 0.9
Mean		7.04 ± 0.08			6.33 ± 0.03
D2	568	10.8 ± 2.3	D2	568	7.2 ± 2.0
	606	12.4 ± 1.7		606	9.4 ± 0.9
	704	11.8 ± 1.4		704	9.4 ± 1.4
	779	9 ± 1.4		779	13 ± 1.1
	955	14.6 ± 1.3		955	8.4 ± 1.2
	1096	11.2 ± 2.8		1096	8.2 ± 1.5
Mean		11.63 ± 0.08			9.26 ± 0.08

densities ranging 7.2 to 9.4/plant were recorded in crop fields at distances of 568–1096 meters far from the wetland borders as compared to low larval densities in the range of 5.4 to 7.4/plant in in crop fields at distance of 82–219 meters from the wetland borders (Table 1). Over all, season 2017A on average registered higher per plant fall armyworm larval densities compared to 15.6/plant in season 2017B (Table 1).

D1 = Distance strata one (0–300 meters from the wetland borders) six crop fields studied and D2 = Distance strata two (500–1100 meters from the wetland borders) six crop fields established. In each distance stratum exact crop field distances in meters from the wetland border line is indicated. SEM-standard error of mean shows variability of means over the sampling time.

Hymenoptera wasp abundance

There was significant ($P < 0.001$) effect of crop field distance from the wetland borders on wasps abundance. Crop fields closer (82–219 meters) to the wetland borders registered higher mean population densities, ranging 15–23 and 12–27 wasps/field, for seasons 2017A and 2017B respectively while fields furthest from the wetland borders (568–1096 meters) had low mean densities, ranging 2–12 and 6–13 wasps/field, in seasons 2017A and 2017B respectively (Figure 3). Additionally, correlation analysis showed a significant negative relationship between fall armyworm incidence, damage severity and larval densities in season 2017B. While strong negative relationship between FAW prevalence with wasp diversity was only observed in season 2017A and not in 2017B (Table 2)

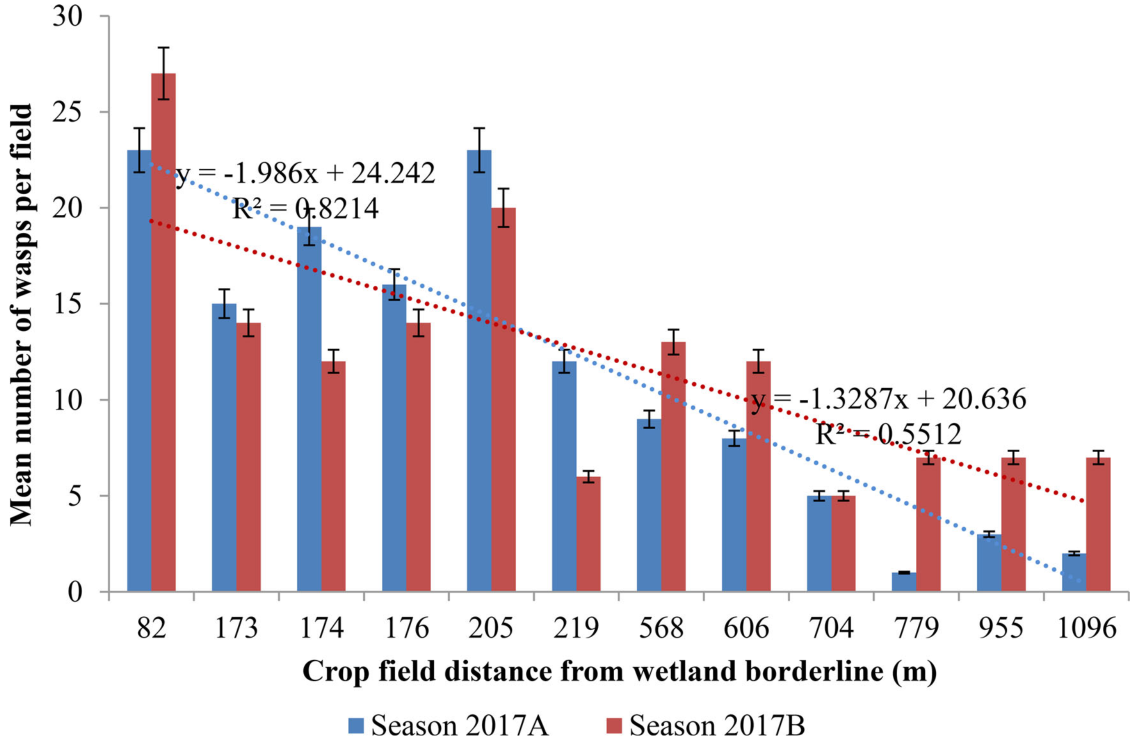

Figure 3. Effect of field distance from the wetland border on relative mean abundance of Hymenopteran wasps in crop fields.

Table 2. Correlational analysis of possible relationship between FAW prevalence and wasp's abundance and diversity.

Study seasons	2017A	2017B	2017A	2017B
FAW prevalence	Wasps abundance		Wasps diversity	
Distance effect	−0.817**	−0.654*	-0.321^{NS}	0.357^{NS}
FAW Incidence	−0.807***	−0.599*	−0.752**	-0.125^{NS}
FAW larval densities	-0.493^{NS}	−0.609*	−0.743**	-0.443^{NS}
FAW damage severity	-0.737^{NS}	−0.623*	−0.726**	-0.217^{NS}

*Significance at 0.05, **significance at 0.01, ***significance at 0.001 and NS-No statistical significance observed.

Furthermore, regression analysis showed that, there was a significant relationship between wasp abundance and crop distance from the wetland boundary. A marked decrease in wasp populations as crop field distance from the wetland borders increased was observed (Figure 3).

Effect of seasons on prevalence of fall armyworm and hymenoptera wasps

Seasons had significant ($P < 0.001$) effect on prevalence of fall armyworm incidence, fall armyworm damage on maize and mean larval densities. But no significant effect of seasons on hymenoptera wasps abundance ($P = 0.155$) and on hymenoptera wasps diversity ($P = 0.606$) was observed. However, generally, high prevalence of fall armyworm was registered in season 2017A than season in season 2017B. Similarly, high hymenoptera wasps abundance and diversity was recorded in season 2017A than in season 2017B (Table 3).

Discussion

Results showed high prevalence of fall armyworm (up to 84% and 69% in seasons 2017A and 2017B respectively) in crop fields further (above 500 meters from the wetland border points), this could be associated with abiotic factors especially high temperatures and low relative humidity. While the low pest prevalence at closer fields to wetland borderline (82–219 meters) maybe due to low temperatures and high relative humidity provided by the wetland border. These factors affect pest populations and fecundity in crop fields closer to wetland borders (Sampson and Kumar 1983; Schulthess et al. 2001; Ndemah et al. 2003).

Fall armyworm prevalence is associated with warm climatic conditions for effective reproduction and ability to persistently cause damage to crops (Georgen et al. 2016). It was observed in our results that on average high larval densities of 14.6/plant and 13/plant in season 2017A and 2017B respectively were recorded in crop fields extending five hundred meters from the wetland border points. Although, moist conditions are reported to be conducive for larval growth into adult moths (Flanders et al. 2011), the emerging adult moths fly distant places to reproduce where warm conditions are favorable and it is possible that crop fields further (above 500 meters) from the wetland border points provided such favorable conditions.

Mailafiya et al. (2010) observed low stem borer abundance in cultivated cereals due to effects of heavy rainfall; equally for fall armyworm, it is likely

Table 3. Effect of cropping season on prevalence of fall armyworm and hymenoptera wasps.

Pest and natural enemy prevalence	Fall armyworm incidence (Mean %)	Fall armyworm damage severity (Mean)	Fall armyworm larval densities (Mean)	Hymenoptera wasp abundance (Mean)	Hymenoptera wasp diversity (Mean)
Season					
2017A	62.00***	4.83***	9.88***	2.42^{NS}	1.18^{NS}
2017B	35.70***	3.22***	7.80***	3.02^{NS}	1.16^{NS}
LSD	8.46	0.62	1.04	0.83	0.09

***Significance at 0.001 and NS-No statistical significance observed.

that crop fields within 300 meters of wetland proximity benefited from low temperatures and high relative humidity that affected the survival and activity of fall armyworm larvae. While the further maize fields from the wetland borders could have provided favourable patches for effective colonization, activity and likelihood of persistence of the pest (Wilson and Simberloff 1969; Connor et al. 2000).

Also the high prevalence of fall armyworm in crop fields further from the wetland borders could be associated with farmers' practice of arbitrarily defining field margins by leaving hedgerows or semi-natural patches thus the hard dispersal barriers (Collinge and Palmer 2002; Cook and Holt 2006) created could have enhanced high colonization and persistence of moths.

Some studies have found crops adjacent to patches of natural habitats to have increased natural enemy populations (Lee et al. 2004; Oberg and Ekbom 2006; Sackett et al. 2009, Rush et al. 2010), decreased pest populations (Paredes et al. 2013) and increased impact of natural enemies on pests (Tscharntke et al. 2002; Thomson and Hoffmann 2009). The wetland borders if relatively undisturbed can provide a haven for a suite of natural enemies that can benefit the adjacent crop fields due to the spillover effects. For example, Hymenopteran parasitoid populations within the wetland borders can be kept high due to abundant floral resources and microclimate, thus their; fecundity, concentration and exportation (Lee et al. 2004; Geneau et al. 2012) to the crop fields at close proximity negatively affected the fall armyworm incidence, damage and larval densities.

Similarly the microclimate provided by wetland borders ensures high humidity that protects parasitoids from desiccation and thereby sustaining their feeding and host finding activities in crop fields adjacent the source habitat (Willmer et al. 1996). Low temperatures have been reported to ensure parasitoid longevity for effective pest control in crops at smaller spatial scales from the adjoining non-crop habitats (Rahim et al. 1991; Bianchi et al. 2006). Thus crop fields closer to the wetland borders could have benefited much higher from parasitoids effects on fall armyworm larval densities and damage severity than crop fields five hundred meters further from the source habitat of wasps.

Field edges influence parasitoid abundance and richness, thus directly affecting parasitism rates and prevalence of their hosts (Holzschuh et al. 2009). Although we have not attempted to quantify the effect of field edge types on FAW prevalence and hymenoptera wasps abundance, field edge type may have influence on parasitism rates by supporting parasitoids richness or diversity and abundance. However, it was observed during this study that crop fields surrounded by grass fallows and more proportion of perennial crops (Fields at distance of 205 and 219 meters from the wetland borders), registered low FAW prevalence (Figures 1 and 2). Possibly, field edges played a crucial role in influencing hymenoptera wasps diversity as was observed in our study.

It has also been reported that natural enemies dispersal can be influenced by distance between source habitat and crops (Bianchi et al. 2009) and agro-ecosystems proximate enough benefit more than those at larger spatial scales. Relatedly, Morandin et al. (2014), Thomson and Hoffman (2010) and Kruess and Tscharntke (2000) found natural enemy abundance and parasitism rates reduce with increase in distance from woody field edges. These findings support the results in this research that; low prevalence of fall armyworm was observed in crop fields within 300 meters closer to the wetland border points and high prevalence in crop fields sampled at spatial scales above five hundred meters from the wetland border points.

Conclusion

Results of this study imply that management of wetland borders sustains biological pest regulation in agro-ecosystems within 300 meters of the natural habitat catchment. However, these effects can be enhanced through management of field margins even at extended distance from the wetland borders. Equally tracking bidirectional movement of predators and parasitoids at temporal scales is crucial in employing practices within agro-ecosystems that promote preservation of beneficial insects and sustain ecosystem services provisioning.

Acknowledgements

The opinions expressed herein are those of the author(s) and do not reflect those of the project management.

Disclosure statement

The authors have not declared any conflict of interests.

Funding

The output of this research was funded by the Regional Capacity building for Sustainable Natural Resource Management and Agriculture Improvement under Climate Change (CAPSNAC) project of Makerere University.

Data availability statement

The data that support the findings of this study are available from the corresponding author [DO] upon reasonable request.

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