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Influence of farmers' practices on fall armyworm infestation levels in maize fields

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Abstract

The fall armyworm (FAW) (*Spodoptera frugiperda*) is an economically important recently introduced pest that is threatening maize production in sub-Saharan Africa. This study aimed to investigate the effect of current smallholder crop production practices on fall armyworm infestation in Uganda. A survey of 87 farms was conducted in cropping systems categorised as: maize monocrop (20 farms), maize+bean intercrop (18), maize+soybean intercrop (19), maize+cassava intercrop (20), and maize mixed with two or more companion crops (10). These were from the districts of Iganga (n=29), Mayuge (n=30) and Namutumba (n=28). The other management practices considered were pesticide application, intercropping intensity, and maize variety grown. Results indicated that FAW incidence of damage in farmers' fields ranged from 64.5 to 99.1%, with moderate severity scores. Namutumba district had the highest incidence and severity whereas Iganga had the lowest. Pesticide application frequency and intercropping system interacted significantly to reduce FAW infestations; as did local varieties, and high intercropping intensity. The multi-crop (>3 crops) system had the lowest FAW infestation, and Maize+bean intercrop edged the other individual companion crop intercrops in lowering infestation by the FAW. These results provide a foundation for building an integrated pest management system for the FAW in Uganda.

Key words: Cropping systems, intercropping intensity, pesticide usage, *Spodoptera frugiperda,* variety

Introduction

The fall armyworm (*Spodoptera frugiperda* J.E. Smith: FAW), is an insect pest of more than 353 plant species, causing damage to economically important cultivated crops such as maize, rice, sorghum, cotton, and vegetable crops (CABI, 2017). Maize is the most preferred host (Abrahams *et al*., 2017). There are two strains of the pest reported in Africa, the maize and rice strains with the former as the more dominant and widespread of the two (Otim *et al*., 2018). *S. frugiperda* is a tropical species adapted to the warm regions of the world with optimum temperature for larval development at about 28°C (Maiga, 2017).

This pest was first reported in Africa in January 2016 in the countries of Benin, Nigeria, Sao Tome and Principe, and Togo (Goergen *et al*., 2016). Presently, the pest has spread to many countries in sub Saharan Africa including South Africa, Ghana, Kenya and Uganda, among others (Sisay *et al*., 2019) and is expected to spread to more countries (Rwomushana *et al*., 2018). The tropical environment and the many host plants on the African continent provide ideal conditions for permanent buildup of significant populations of the fall army worm (Abrahams *et al*., 2017; Reddy *et al*., 2020).

In Africa, it is estimated that FAW infestation causes annual losses of up to 17.7 million tonnes of maize (Rwomushana *et al*., 2018). Losses of 40% in maize yield are attributed to the FAW (CABI, 2017)); however different countries post different figures, for instance, Kumela *et al*. (2018) reported a 47.3% loss in Kenya, 9.4% in Zimbabwe (Baudron *et al*., 2019), and 22–67% in Ghana and Zambia (Day *et al*., 2017). There are no empirical yield loss figures for Uganda, but losses in the range of 15-75% are stated for maize in the different districts (Tambo *et al*., 2019).

Research on management measures for the invasive FAW in Uganda are in the early stages with chemical control being the option of choice to mitigate the effects of the pest. However, chemical control comes with the drawbacks of increased production costs, irregular success due to limited knowledge in product choice and timing of application, and environmental concerns (Togola *et al*., 2018). Intercropping and manipulation of planting time are among low cost alternative management measures recommended for farmers (Prasanna *et al*., 2018). For instance, most farmers in Uganda grow their maize intercropped with other crops; however, the role of crop diversification in mitigating FAW is yet to be investigated. The objective of this study was to quantify the effect of specific farmers' practices on FAW infestation.

Materials and methods

The study was conducted in the districts of Namutumba, Iganga and Mayuge in eastern Uganda where the bulk of Uganda's maize is produced. Namutumba is located at an altitude of 1134 m above sea level (m.a.s.l), Latitude 00°50'06''N, Longitude 33°41'06''E, receives a mean annual rainfall of 1100 mm, and has mean annual temperatures of 25 °C (Ajak *et al*., 2018). Mayuge is at 1158 m.a.s.l, Latitude 00° 27' 33''N, Longitude 33° 38' 49''E, with mean annual rainfall of 1000 mm and mean annual temperatures 25 °C. Iganga is at 1081 m.a.s.l, Latitude 00° 36' 33''N, Longitude 33° 28' 7''E, with mean annual rainfall of 1100 mm, and mean annual temperatures 25 °C. Over 80% of the farmers in these three districts practice subsistence farming (UBOS, 2011).

Research design

A survey was conducted to establish the status of FAW infestation in the three study districts. This was done in two main maize producing sub-counties of each district, as guided by information from the respective District Agricultural Production Offices. Sample size was determined using a formula by Yamane (1967). Maize farmers were categorised based on their maize cropping systems, whereby the following categories were considered for this study; (i) maize monocrop, (ii) Maize+bean intercrop, (iii) Maize+soybean intercrop, (iv) Maize+cassava intercrop and (v) maize mixed with two or more companion crops. Twenty representatives of each maize cropping category were planned initially; but a total of 87 farmers were available based on the criteria for this study. A total of 20 farmers had maize monocrop, 18 had maize+ bean intercrop, 19 had maize+ soybean intercrop, 20 had maize+ cassava intercrop, and 10 had maize mixed with two or more companion crops. The maize at the time of the survey was 2-2.5 months after planting.

FAW data collection procedures

Data collection from the 87 farming households was done using targeted checklists on farmer practices, and field observations/measurements. Data collected from the checklists and observations included: type of cropping system, crops grown in intercrop, pesticide application frequency, and crop parameters (intercrop intensity/ pattern, variety).

The variety grown was determined by asking the farmer the kind of variety they had grown and these were grouped into local, Hybrid or open pollinated variety. Pesticide application frequency was estimated by asking the farmer, how many times he/she had sprayed the garden of maize with an insecticide to control the FAW. Maize variety and type of the cropping system and the crops grown in the intercrop were recorded by physically inventorying them in the field. Intercropping pattern was assessed in the field by counting the number of plant rows and how they were arranged in between rows of maize.

Biological information on incidence and severity of FAW damage on each study farm was collected. This was done by randomly throwing a 4 m x 4 m quadrant, five times in each of the study fields. Data were collected on ten plants selected randomly within each quadrant, giving a total of 50 plants per field.

Fall army worm severity of damage on foliage was determined using the scale of 1-5 (Modified from Lima *et al*., 2010), where 0 = no damage, 1 = scraped leaves , 2 = leaves with slight extensive holes, 3 = leaves with lesions, 4 = Severe damage with most leaves tattered ; and 5 = Very severe damage with 60% or 90% of leaves completely destroyed. The Incidence of FAW damage was calculated as percentage of infested plants out of total number of plants sampled in each study quadrant.

Data analysis

Genstat (12th Edition) statistical package was used to generate a one way Analysis of Variance (ANOVA) using the generalised linear model (GLM) to determine the influence of cropping system (1= maize monocrop, 2= Maize+beans, 3=Maize+soybean, 4=Maize+cassava, 5=maize with two or more intercrops); pesticide application frequency (1 = no pesticide, 2= 1-2 times a season, 3 = 3-4 times); type of maize variety grown (2=OPV, 3=local, 4=hybrid); and intercropping pattern/intensity (1=none/mono, 2=Low, 3=High); separately, on fall armyworm incidence and damage. Each district's data was analysed separately due to differences that may be in biophysical conditions that are known to affect pest's dynamics (Khaliq *et al*., 2014). Significant means were separated using Fisher's protected Least Significant Difference at 5 %.

To test for possible interactions among factors:, cropping system (this time 1= maize monocrop vs. 2= intercrop collectively) and pesticide application frequency were tested as main effects in a GLM; whereas variety, maize growth stage, and crops in the field (1= maize monocrop, 2= Maize+beans, 3=Maize+soybean, 4=Maize+cassava, 5=maize with two or more intercrops) were included as covariates. Significant means were separated using Fisher's protected Least Significant Difference at 5 %.

Results

Effect of intercropping system on incidence and severity of damage of the FAW in different districts

Fall armyworm incidence of damage in farmers' fields ranged from 64.5% to 99.1% with moderate severity scores of 1-2. Namutumba district had the most occurring infestation with a mean of 94.5% of sampled plants showing damage symptoms, whereas Iganga had the lowest at 78.5% (Table 1). The effect of cropping system, including different intercrop types, on FAW incidence of damage and severity of damage was significant (P< 0.05). In all studied districts, systems with maize

Table 1. Effect of intercropping system on FAW incidence of damage and severity on maize

District	Type of intercrop	Mean FAW damage score (0-5) (Means ± SEM)	Mean % FAW damage 1ncidence (Means ± SEM)
Iganga	Maize monocrop	1.66^{a}±0.15	86.86^{a}±3.20
	Maize + bean	0.92^{b}±0.10	74.00^{a}±5.48
	Maize + soybean	1.11^{b}±0.09	85.60^{a}±3.66
	Maize + cassava	1.48^{ab}±0.16	83.67^{a}±5.18
	Maize + more than two crops	0.89^{b}±0.12	64.86^{b}±5.85
	Mean	1.23	78.50
	LSD	0.40	14.9
Mayuge*	Maize monocrop	2.67^{a}±0.14	99.14^{a}±0.48
	Maize + bean	1.67^{b}±0.12	93.25^{b}±2.81
	Maize + soybean	1.15^{b}±0.13	81.00^{c}±4.85
	Maize + cassava	1.51^{b}±0.15	86.89^{bc}±3.11
	Mean	1.75	90.30
	LSD	0.38	8.8
Namutumba	Maize monocrop	2.60^{a}±0.20	98.33^{a}±0.84
	Maize + bean	1.10^{c}±0.14	86.50^{b}±4.92
	Maize + soybean	1.88^{b}±0.12	97.38^{a}±1.17
	Maize + cassava	1.40^{c}±0.13	94.80^{a}±1.74
	Maize + more than two crops	1.29^{c}±0.19	87.33^{b}±4.00
	Mean	1.77	94.49
	LSD	0.48	6.73

Note: Means in the same column with similar letters are not significantly different at $P<0.05$; *in Mayuge, the system of maize + more than two companion crops was not encountered

intercropped with crops such as bean, cassava, soybean had significantly lower FAW incidence and severity than fields of the maize monocrop (Table 1) except for FAW incidence in Iganga and Namutumba where there were no differences between the maize in the monocrop and maize in the intercrops of soybean and cassava. Generally, the Maize+bean intercrop and Maize+two or more intercrops were the systems that had a notable lowering effect on infestation by the FAW (Table 1).

Interaction between different factors on FAW incidence and severity on maize
In the analysis of district, cropping system and pesticide application/use frequency as main effects and variety, maize growth stage, and crops in the field as covariates; results indicated that the district*cropping system*pesticide application frequency interaction significantly influenced FAW foliage damage severity ($P<0.05$) but not FAW damage incidence. However, FAW damage incidence was significantly influenced by the cropping system*pesticide application frequency interaction ($P\leq 0.05$). The results on FAW damage severity showed that maize in intercrops generally had lower severity scores than in monocrops in all districts (Fig. 1). Surprisingly, it was only in intercrop systems where pesticide application/use frequency had an impact in Mayuge and Namutumba; where the most frequent applications of more than 3 times a season had the lowest FAW severity (Fig. 1). With regard to FAW damage incidence, the results show that incidence increased with an increase in frequency of pesticide application/use in the maize monocrops but the frequency of 3-4 times a season in the intercrop system had the lowest recorded FAW incidence (Fig. 2).

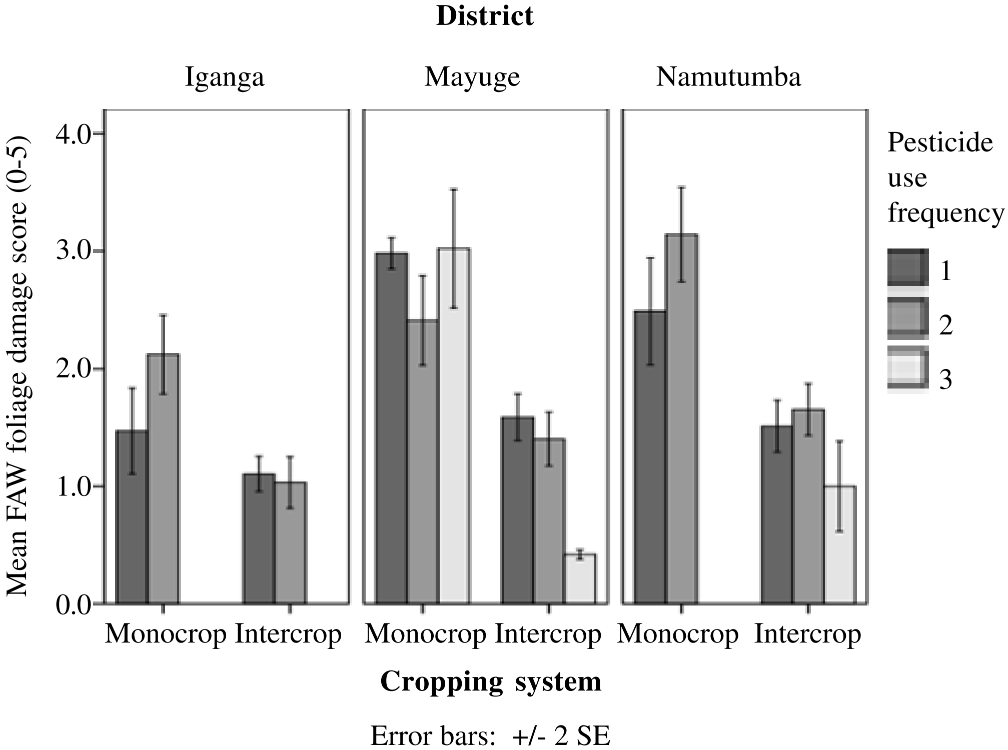

Figure 1. Effect of the interaction between district, cropping system and pesticide application frequency on FAW damage severity (where 1 = no pesticide, 2= 1-2 times a season, 3 = 3-4 times); missing result show that the pesticide regime was not practiced in that district.

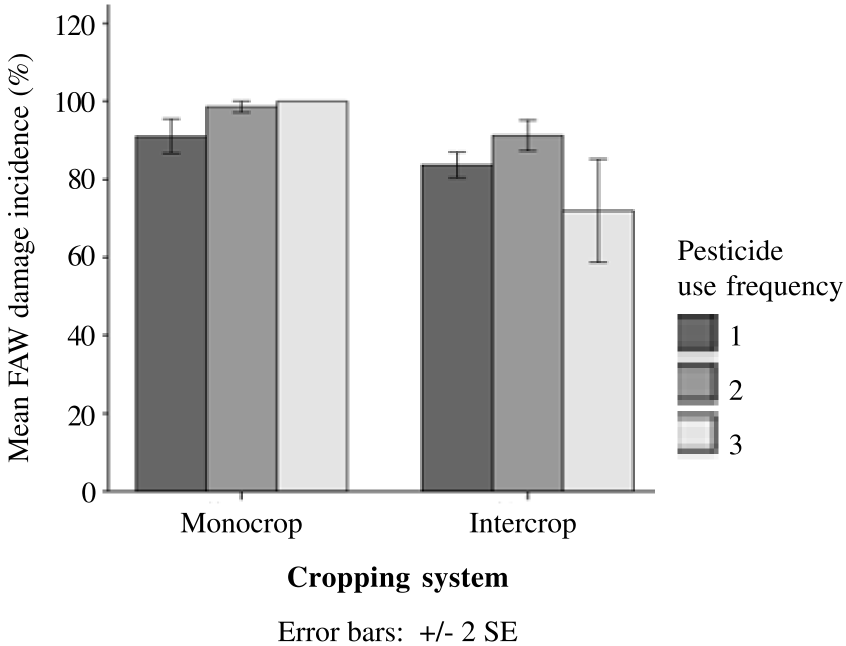

Figure 2. Effect of the interaction between cropping system and pesticide application frequency on FAW damage incidence (where 1 = no pesticide, 2= 1-2 times a season, 3 = 3-4 times).

Effect of intercropping pattern on FAW incidence of damage and severity on maize in different districts

Intercropping pattern/intensity significantly ($P < 0.05$) affected FAW incidence of damage and severity on maize. In all studied districts, in maize fields where intercrop intensity was high, there was less FAW damage severity compared to the monocrop (Table 2). For incidence, maize plants in intercrops with less companion crop intensity, the effect was not distinct from the monocrop except in Iganga where there were discernible differences (Table 2).

Maize variety grown versus FAW incidence of damage and severity

Type of maize variety grown significantly ($p < 0.05$) affected FAW incidence of damage and severity on maize in all districts except for FAW incidence in Namutumba. In all districts, farmers who had grown local variety experienced lower fall armyworm severity of damage and incidence of damage than those with open pollinated varieties and Hybrids with an exception in Iganga where the FAW incidence was lowest in Hybrids (Table 3). In most cases, there was no significant difference in FAW damage incidence and severity between the open pollinated varieties (OPV) and Hybrids.

Table 2. Effect of intercropping intensity/pattern on FAW incidence of damage and severity on maize

District	Intercropping pattern intensity	Mean FAW damage score (0-5) (Means ± SEM)	Mean % FAW damage 1ncidence (Means ± SEM)
Iganga	Monocrop	1.66^{a}±0.15	86.86^{a}±3.20
	Low	1.19^{b}±0.13	73.60^{b}±4.42
	High	1.03^{b}±0.07	77.38^{b}±3.67
	Mean	1.23	78.5
	LSD	0.39	11.49
Mayuge	Monocrop	2.58^{a}±0.15	99.00^{a}±0.56
	Low	1.91^{b}±0.12	95.25^{a}±1.68
	High	1.36^{c}±0.10	84.50^{b}±2.75
	Mean	1.75	90.3
	LSD	0.36	8.0
Namutumba	Monocrop	2.60^{a}±0.20	98.33^{a}±0.84
	Low	1.65^{b}±0.09	95.84^{a}±1.19
	High	1.37^{b}±0.13	89.25^{b}±2.74
	Mean	1.77	94.5
	LSD	0.37	5.15

Note: Means in the same column with similar letters are not significantly different at $P<0.05$. Where: Low = 1-2 lines of intercrop to a line of maize, High = ≥ three lines of intercrop to a line of maize

Discussion

Effect of farmers' practices on FAW damage incidence and severity in three districts

In this study, the farmers' practices investigated were cropping system used, frequency of pesticide application, maize variety grown, and intercropping pattern/intensity of the companion crop. For cropping system, results varied by district, in Namutumba and Mayuge the effect of intercropping was significant on both fall armyworm damage parameters of damage incidence and severity but not so in Iganga. Where the effect was significant, there was a reduction effect on the fall armyworm damage compared to where maize was grown as a monocrop. Intercropping with non-host crops has been demonstrated to reduce insect pests in maize (Firake *et al.*, 2019; Midega *et*

Table 3. Effect of type maize variety grown on FAW incidence of damage and severity on maize

District	Maize variety	Mean FAW damage score (0-5) (Means ± SEM)	Mean % FAW damage 1ncidence (Means ± SEM)
Iganga	Local	0.78[b]±0.11	82.70[a]±3.12
	Hybrid	1.25[a]±0.13	60.80[b]±7.68
	OPV	1.40[a]±0.10	81.67[a]±2.97
	Mean	1.23	78.50
	LSD	0.26	12.68
Mayuge	Local	1.18[b]±0.20	83.20[b]±0.92
	Hybrid	1.87[a]±0.13	90.48[ab]±4.96
	OPV	1.83[a]±0.10	98.00[a]±1.93
	Mean	1.75	90.30
	LSD	0.45	9.40
Namutumba	Local	1.39[b]±0.14	91.38[a]±1.16
	Hybrid	1.93[a]±0.12	96.29[a]±2.28
	OPV	2.02[a]±0.15	96.18[a]±1.64
	Mean	1.77	94.50
	LSD	0.40	5.22

Note: Means in the same column with similar letters are not significantly different at P<0.05

al., 2018, Kebede *et al*., 2018; Agboka *et al*., 2006; Sekamatte *et al*., 2003). This may be attributed to the effects of companion crops on the pests through physical interruption in movement from one plant to another, and increased *in situ* protection by natural enemies in such diversified fields (Parker *et al*., 2013). The intercrops reduce the pest damage through disruption of pest host location and hence reducing the number of eggs laid on the crop (Harrison *et al*., 2019). Earlier, Gianoli *et al*. (2006) postulated that the additional time and energy the pest must spend in searching for an acceptable plant due to interruptions by the plants it cannot feed on may lead to reduction in pest numbers. The advantage to the host plants ensues from the increased time and energy the herbivorous insect needs to cause crop damage.

Increasing plant diversity by intercropping with pulses and ornamental flowering plants has been reported to increase occurrence of various natural enemies (Firake, 2019).

The presence of other plants in the main crop can provide a number of resources for natural enemies including shelter, food, and information on the location of their herbivorous prey (Bugg and Waddington, 1994; Ratnadass *et al*., 2012).

In this study, the difference in FAW damage severity among the different intercrops used as companion crops gives a slight edge to the common bean in reducing FAW damage. This is in line with the results of Midega *et al.* (2018) who reported lower FAW damage in maize+bean intercropped fields. Legumes are believed to 'push' lepidopteran pests via chemical ecology (volatiles) in push pull technology (Kumela *et al*., 2019b). Similarly, Kebede *et al.* (2018) found common bean to be as effective as *Desmodium* spp. in repelling *Buseola fusca* which is another Lepidopteran pest that infests cereals.

The three way interaction of district*cropping system*pesticide application frequency was significant on FAW damage severity while it was not significant on FAW damage incidence. Also, the two-way interaction of cropping system*pesticide application frequency influenced FAW damage severity and damage incidence significantly. What stood out was that growing maize in an intercrop system integrated with pesticide usage had a reducing effect on FAW damage whereas using pesticide on monocropped maize was not effective in reducing FAW damage. This could be due to the additive effects of the two control methods where the two support each other as an integrated approach as guided in Prasanna *et al.(*2018) on use of a combination of methods to combat the fall armyworm. Therefore, this raises a research gap on what methods should be combined to better manage the fall armyworm in a sustainable way.

Application of pesticides tended to promote higher FAW damage in monocrops than no application at all. These results of this study concur with results obtained by (Baudron *et al*., 2019) who reported higher FAW densities in plots that received the pesticides than those that did not. Similarly, Kumela *et al*., (2019a) showed slight efficacy of pesticides applied against FAW in Kenya. This may probably be due to usage of a wrong dosage, wrong mixing, inappropriate pesticides applied, and/or wrong timing of application as suggested by Baudron *et al.* (2019). In fact, the assertion of Karungi *et al.* (2011) that insecticide misuse through adulteration, improper repackaging, and use of unverified synthetic insecticides in Africa may also be a contributing factor towards the results observed in this study against *S. frugiperda*.

Also, since the fall armyworm larvae normally hide inside the whorl, if the pesticide is not targeted to get inside it, there is a likelihood of not getting desired contact with the larvae (Njuguna *et al*., 2021). More still, since the fall armyworm is a nocturnal pest, chances of being affected by pesticides sprayed during day are lower. Another explanation would be that the older larvae stay inside the funnel or developing reproductive structures, such as maize cobs that may shield them from pesticide exposure. This behaviour makes FAW and other cryptic Lepidoptera control by pesticides more difficult, especially where efficacy depends upon contact (Bateman *et al.*, 2018). Therefore, it is important to sensitise farmers on the proper methods of pesticide usage to circumvent inefficacy of pesticides, health risks, and cases of resistance development.

Results on the effect of intercropping pattern/intensity on FAW damage severity generally showed that the higher the intensity of the intercrop in maize fields, the lower the FAW infestation. The lower levels of damage severity could be as a result of increased distance between the maize plants that affects the movement of the pest, especially the feeding larvae. Therefore, in field where there were more than two lines of the intercrop the separation from one maize line to another could have affected their ease of movement to locate the host plant as larvae have limited movement capacity. These results are in line with Degri *et al*. (2014), who reported a lower stem borer infestation in millet and groundnut system at 1:2 ratio compared to the 1:1 ratio and monocrop. This therefore creates a need for research to ascertain the density of the appropriate intercrop that will give the best results in managing the fall armyworm infestations.

The type of maize variety grown showed an effect on fall armyworm infestation with the local variety generally registering the lowest compared to hybrids and open pollinated varieties. Local varieties constitute landraces with relatively smaller cobs with highly multicolored grain that have been passed across many generations. The lower infestation on local varieties may be due to the fact that they are adapted to production without external inputs, and have appreciable levels of resistance, or are less palatable to pests (Tefera *et al*., 2016). Williams *et al*. (2006) reported that plant characteristics like density of leaf hairs or density of cuticular wax layer were reported to lessen foliar damage. Also, physical features of plant organs or tissues and secondary toxic metabolites can influence host-plant selection behavior and are part of the array of direct defenses of the plant; for instance, trichomes, wax crystal structures, leaf thickness and toughness, and silica content may cause avoidance behavior in insects (Andama *et al*., 2020). And these normally vary among different crop varieties causing differences in responses to damage caused by insect pests. A study by Williams *et al*. (1998) reported that maize varieties resistant to FAW showed less leaf damage, and larvae feeding. There is an urgent need for research focusing of identifying sources of resistance to the FAW in local settings that can help boost management strategies of cereal farmers.

Conclusion

This study on effect of farmers' management practices on the infestation levels of the fall armyworm showed that incidence of FAW in farmers' field is high and that intercropping especially with high companion crop stands has a lowering effect on incidence and severity of the pest. The effect of chemical insecticides was dependent on cropping system with the intercropped system interacting with pesticide usage to reduce FAW damage. Local maize varieties generally had lower FAW damage than OPV and hybrid counterparts.

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References

Abrahams, P., Beale, T., Cock, M., Corniani, N., Day, R., Godwin, J., Murphy, S., Richards,G. and Vos, J. 2017. Fall armyworm status. Impacts and control options in Africa: Preliminary Evidence Note (April). *CABI, UK*. Retrived from. https://www.cabi.org/Uploads/isc/Dfid%20Faw%20 Inception % 20 Report April 2017 final. Pdf. Accessed on June 24, 2019.

Agboka, K., Gounou, S. and Tamo, M. 2006. The role of maize-legumes-cassava intercropping in the management of maize ear borers with special reference to *Mussidia nigrivenella* Ragonot (Lepidoptera: Pyralidae). In: *Annales de la Société entomologique de France* 42 (3): 495-502.

Andama, J. B., Mujiono, K., Hojo, Y., Shinya, T. and Galis, I. 2020. Nonglandular silicified trichomes are essential for rice defense against chewing herbivores. *Plant, Cell & Environment* 43(9): 2019-2032.

Bateman, M. L., Day, R. K., Rwomushana, I., Subramanian, S., Wilson, K., Babendreier, D. and Edgington, S. 2021. Updated assessment of potential biopesticide options for managing fall armyworm (*Spodoptera frugiperda*) in Africa. *Journal of Applied Entomology* 145(5): 384-393.

Baudron, F., Zaman-Allah, M. A., Chaipa, I., Chari, N. and Chinwada, P. 2019. Understanding the factors influencing fall armyworm (Spodoptera frugiperda JE Smith) damage in African smallholder maize fields and quantifying its impact on yield. A case study in Eastern Zimbabwe. *Crop Protection* 120: 141-150.

Bugg, R. L. and Waddington, C. 1994. Using cover crops to manage arthropod pests of orchards: A review. *Agriculture, Ecosystems and Environment* 50 (1): 11–28.

CABI. 2017. New report reveals cost of Fall Armyworm to farmers in Africa, provides recommendations for control. Retrived from: https://www.cabi.org/news-article/new-report-reveals-cost-of-fall-armyworm-to-farmers-in-africa-provides-recommendations-for-control/. Accessed on May 22, 2021.

Day, R., Abrahams, P., Bateman, M., Beale, T., Clottey, V., Cock, M. and Gomez, J. 2017. Fall armyworm: Impacts and Implications for Africa. *Outlooks on Pest Management* 28 (5): 196-201.

Degri, M. M., Mailafiya, D. M. and Mshelia, J. S. 2014. Effect of intercropping pattern on stem borer infestation in pearl millet (*Pennisetum glaucum* L.) grown in the Nigerian Sudan Savannah. *Advances in Entomology* 2:81-86.

Firake, D.M., Behere, G.T., Babu, S. and Prakash, N. 2019. Fall Armyworm: Diagnosis and Management (An extension pocket book). Indian Council of Agricultural Research Complex for NEH Region, Umiam-793103, Meghalaya, India. 48. Retrived from, https://www.researchgate.net/publication/335620412. Accessed on June 04, 2021.

Gianoli, E., Ramos, I., Alfaro-Tapia, A., Valdéz, Y., Echegaray, E. R. and Yábar, E. 2006. Benefits of a maize–bean–weeds mixed cropping system in Urubamba Valley, Peruvian Andes. *International Journal of Pest Management* 52 (4): 283-289.

Goergen, G., Kumar, P. L., Sankung, S. B., Togola, A. and Tamò, M. 2016. First report of outbreaks of the fall armyworm spodoptera frugiperda (J E Smith) (Lepidoptera, Noctuidae), a new alien invasive pest in West and Central Africa. *PLoS ONE* 11 (10): 1–9.

Harrison, R. D., Thierfelder, C., Baudron, F., Chinwada, P., Midega, C., Schaffner, U. and van den Berg, J. 2019. Agro-ecological options for fall armyworm (*Spodoptera frugiperda* JE Smith) management: Providing low-cost, smallholder friendly solutions to an invasive pest. *Journal of Environmental Management* 243: 318-330.

Hruska, A. J. and Gould, F. 1997. Fall armyworm (Lepidoptera: Noctuidae) and *Diatraea lineolata* (Lepidoptera: Pyralidae): Impact of larval population level and temporal occurrence on maize yield in Nicaragua. *Journal of Economic Entomology* 90 (2): 611–622.

Karungi, J., Kyamanywa, S., Adipala, E. and Erbaugh, M. 2011. Pesticide utilisation, regulation and future prospects in small scale horticultural crop production systems in a developing country. pp. 19–34. In: Stoytcheva, M. (Ed.), Pesticides in the modern world. InTechopen, London.

Kebede, Y., Baudron, F., Bianchi, F. and Tittonell, P. 2018. Unpacking the push-pull system: Assessing the contribution of companion crops along a gradient of landscape complexity. *Agriculture, Ecosystems & Environment* 268: 115-123.

Khaliq, A., Javed, M., Sohail, M. and Sagheer, M. 2014. Environmental effects on insects and their population dynamics. *Journal of Entomology and Zoology Studies* 2 (2): 1-7.

Kumela, T., Simiyu, J., Sisay, B., Likhayo, P., Mendesil, E., Gohole, L. and Tefera, T. 2019a. Farmers' knowledge, perceptions, and management practices of the new invasive pest, fall armyworm (*Spodoptera frugiperda*) in Ethiopia and Kenya. *International Journal of Pest Management* 65 (1): 1-9.

Kumela, T., Mendesil, E., Enchalew, B., Kassie, M. and Tefera, T. 2019b. Effect of the push-pull cropping system on maize yield, stem borer infestation and farmers' perception. *Agronomy* 9(8):1-13.

Lima, M. S., Silva, P. S. L., Oliveira, O. F., Silva, K. M. B. and Freitas, F. C. L. 2010. Corn yield response to weed and fall armyworm controls. *Planta Daninha* 28 (1): 103-111.

Maiga, I. 2017. General information note on fall armyworm *Spodoptera frugiperda* J.E. Smith Entomologist AGRHYMET Regional Centre/CILSS. Retrived from. http://www.agrhymet.ne/eng/PDF/General%20information%20note%20on%20fall%20armyworm%20 Spodoptera%20 frugiperda%20J-Final%20version.pdf. Accessed on March 04, 2020.

Midega, C.A., Pittchar, J.O., Pickett, J.A., Hailu, G.W. and Khan, Z.R. 2018. A climate-adapted push pull system effectively controls fall armyworm, *Spodoptera frugiperda* (JE Smith), in maize in East Africa. *Crop Protection* 105: 10-15.

Njuguna, E., Nethononda, P., Maredia, K., Mbabazi, R., Kachapulula, P., Rowe, A. and Ndolo, D. 2021. Experiences and perspectives on Spodoptera frugiperda (Lepidoptera: Noctuidae) management in Sub-Saharan Africa. *Journal of Integrated Pest Management* 12 (1): 1-9.

Otim, M. H., Tay, W. T., Walsh, T. K., Kanyesigye, D., Adumo, S., Abongosi, J. and Asea, G. 2018. Detection of sister-species in invasive populations of the fall armyworm *Spodoptera frugiperda* (Lepidoptera: Noctuidae) from Uganda. *PloSOne* 13 (4): 1-18.

Parker, J. E., Snyder, W. E., Hamilton, G. C. and Rodriguez-Saona, C. 2013. Companion planting and insect pest control. (1-30). Rijeka, Croatia: InTech. Retrived from. https://www.intechopen.com/books/weed-and-pest-control-conventional-and-new-challenges/companion-planting-and-insect-pest-control. Accessed on May 10, 2021.

Prasanna, B. M., Huesing, J. E., Eddy, R. and Peschke, V. M. 2018. Fall armyworm in Africa: A guide for Integrated Pest Management, 1st Edition. Mexico, CIMMYT.

Ratnadass, A., Fernandes, P., Avelino, J. and Habib, R. 2012. Plant species diversity for sustainable management of crop pests and diseases in agroecosystems/ *: A Review Agronomy for Sustainable Development* 32 (1): 273-303.

Reddy, K. J. M., Kumari, K., Saha, T. and Singh, S. N. 2020. First record, seasonal incidence and life cycle of fall armyworm, Spodoptera frugiperda (JE Smith) in maize at Sabour, Bhagalpur, Bihar. *Journal of Entomology and Zoology Studies* 8 (5): 1631-1635.

Rwomushana, I., Bateman M., Beale T., Beseh P., Cameron K., Chiluba M., Klottey V., Davis T., Day R., Early R., Godwin J., Gonzalez-Moreno P., Kisiime M., Kenis M., Makale F., Mugambi I., Murphy S., Nunda W., Phiri N., Pratt C. and Tambo J. 2018. Fall armyworm: impacts and implications for Africa. Evidence note update. CABI, Wallingford, UK, pp.51. Retrived from. https://www.invasivespecies.org/wp-content/uploads/sites/2/2019/02/FAW-Evidence-Note-October-2018.pdf. Accessed on February 02, 2019.

Sekamatte, B.M. M. Ogenga-Latigo, M. W. and Russell-Smith, A. 2003. Effects of maize-legume intercrops on termite damage to maize , activity of predatory ants and maize yields in Uganda. *Crop Protection 22*: 87–93.

Sisay, B., Tefera, T., Wakgari, M., Ayalew, G. and Mendesil, E. 2019. The efficacy of selected synthetic insecticides and botanicals against fall armyworm, Spodoptera frugiperda, in maize. *Insects* 10 (2): 1-14.

Tambo, J. A., Aliamo, C., Davis, T., Mugambi, I., Romney, D., Onyango, D. O. and Byantwale, S. T. 2019. The impact of ICT-enabled extension campaign on farmers' knowledge and management of fall armyworm in Uganda. *PloS one* 14 (8): 1-21.

Tefera, T., Mugo, S., Mwimali, M., Anani, B., Tende, R., Beyene, Y. and Prasanna, B. M. 2016. Resistance of Bt-maize (MON810) against the stem borers *Busseola fusca* (Fuller) and *Chilo partellus* (Swinhoe) and its yield performance in Kenya. *Crop Protection* 89:202-208.

Togola, A., Meseka, S., Menkir, A., Badu-Apraku, B., Boukar, O., Tamò, M. and Djouaka, R. 2018. Measurement of pesticide residues from chemical control of the invasive *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in a maize experimental field in Mokwa, Nigeria. *International Journal of Environmental Research and Public Health*, 15 (5):1-11.

UBOS. 2011. Uganda Bureau of Statistics. The 2011 Statistical Abstract http://www.agriculture.go.ug/userfiles/ Statistical%20Abstract%202011.pdf. Accessed on 20th May 2021.

Williams, W. P., Buckley, P. M., Sagers, J. B. and Hanten, J. A. 1998. Evaluation of transgenic corn for resistance to corn earwonn (Lepidoptera: Noctuidae), fall armyworm (Lepidoptera: Noctuidae), and southwestern corn borer (Lepidoptera: Crambidae) in a laboratory bioassay l, 2. *Journal of Agricultural Entomology* 15 (2): 105-112.

Williams, W. P., Buckley, P. M. and Daves, C. A. 2006. Identifying resistance in corn to southwestern corn borer (Lepidoptera: Crambidae), fall armyworm

(Lepidoptera: Noctuidae), and corn earworm (Lepidoptera: Noctuidae). *Journal of Agricultural and Urban Entomology* 23 (2): 87-95.

Yamane, T. 1967. Statistics: An Introductory Analysis, 2nd Ed., New York: Harper and Row.