Journal of Agriculture and Environment
Vol. 20 No. 1, 2024: 253-264

Economic injury levels of fall armyworm (*Spodoptera frugiperda* Smith) at early-whorl vegetative growth stage of quality protein maize variety

M.S. Usman[1], R.S. Adamu[1], I. Onu[1], E. Kogi[2], N. Musa[1] and I.A. Ahmed[3]

[1]Department of Crop Protection, Faculty of Agriculture, Institute for Agricultural Research, Ahmadu Bello University, Zaria
[2]Department of Zoology, Faculty of Life Sciences, Ahmadu Bello University, Zaria
[3]Samaru College of Agriculture, Division of Agricultural Colleges, Ahmadu Bello University, Zaria

ABSTRACT

Screen-house experiments were conducted in 2020 and 2021 wet seasons to determine the Economic Injury Levels (EIL) of fall armyworm (*Spodoptera frugiperda* Smith) at the early-whorl vegetative growth stage (V4) of SAMMAZ 36 quality protein maize (QPM) variety at Samaru, Zaria, Nigeria. The variety grown in different plastic pots was placed in separate wooden cages at the screen-house and artificially infested with different larval densities (0, 2, 4 and 6) of fall armyworm (FAW) per plant at two weeks after emergence. The experiments were laid out in a completely randomized design (CRD) and repeated three times. Relationship between FAW larval densities and cob damage rating, grain yield (kg/ha) and percent yield losses were determined by coefficient of determination (R^2) and regression equation. The results showed that plants with zero infestation had the highest grain yield, and the grain yields of infested plants decreases with increase in number of FAW larvae. Infestation with 6 larvae per plant in 2020 and 2021 experiments resulted in yield losses of 28.2 and 26.1%, respectively. Regression of grain yield and FAW larval densities was negative and linear, for the early-whorl growth stage of SAMMAZ 36 in both years. The EIL values determined from this study were 4.44 and 3.32 FAW larvae per plant in 2020 and 2021 seasons, respectively. Based on these findings, when FAW densities of at least three larvae per plant are detected at the early-whorl (21- 28 days after emergence) vegetative growth stage of maize, control measures should be initiated to prevent FAW population build up and economic damage.

Keywords: Economic injury levels; fall armyworm; early-whorl vegetative growth stage; quality protein maize.

INTRODUCTION

Maize (*Zea mays* L.) also known as corn belongs to the family Poaceae. It accounts for almost half of the calories and protein consumed in eastern and southern Africa, and one-fifth in West Africa (Macauley, 2015). Over the years, maize has become an important crop

https://www.ajol.info/index.php/jagrenv
ISSN: 1595-465X (Print) 2695-236X (Online)
Correspondence: merryussy@gmail.com
https://dx.doi.org/10.4314/jagrenv.v20i1.24

in Nigeria, taking over acreages from traditional crops such as millet and sorghum (Kamara *et al*., 2020). The nutritional quality of maize is determined by the amino acid make-up of its protein. Amino acids serve as the building blocks for proteins. Maize contains all the ten essential amino acids (arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine) in varying amounts (Nurit and Palacios-Rojas, 2006). However, while maize may provide a rich source of some of these essential amino acids, it is a poor source of others. Non-quality protein maize (non-QPM) commonly grown and consumed are deficient in two essential amino acids, lysine and tryptophan, therefore have poor nutritive value (Usman, 2014). As a result, malnutrition due to inadequate protein intake is therefore widespread (Bjarnason and Vasal, 1992). Quality protein maize (QPM) has high nutritive value due to the presence of higher amounts of lysine and tryptophan, thus the use of QPM varieties helps to reduce nutritional related diseases and death among young children, pregnant and lactating mothers, the sickly and many low-income families especially in developing countries including Nigeria (Bressani, 1992). In general, a sample with more than 0.070 % of tryptophan is considered QPM (Nurit and Palacios-Rojas, 2006).

Lower yields of maize have been attributed to a number of biotic and abiotic factors (IAR, 2021) including insects, diseases, poor soil fertility and drought (Tufa and Ketema, 2016), but amongst them the losses caused by the insect pests is the major one (IAR, 2022). The FAW *Spodoptera frugiperda* (Lepidoptera: Noctuidae) is a devastating insect pest that causes damage to economically important crops. It is a polyphagous insect that feeds on maize, sorghum, sugarcane, many legumes and cotton (Pogue, 2002). It causes severe damage to cereals (Goergen *et al.*, 2016; Roger *et al.*, 2017; Prassana *et al.*, 2018) but it appears to cause more damage to maize in West and Central Africa than most other African countries (IITA, 2016). Losses due to the fall armyworm attack on maize can reduce grain yield up to 34% (Lima *et al.*, 2010). In January 2016, the FAW was reported for the first-time causing damage to maize on the African continent (Goergen *et al*., 2016; Sisay, 2018). It has now become the most important and destructive pest (Assefa and Ayalew, 2019) in reducing maize production in Nigeria and Africa (Abrahams *et al.*, 2017; Kamara *et al*., 2020). The presence of this new invasive pest in West and Central Africa adds to the threat already caused by native Lepidopteran maize stalk/stem borers of economic importance, in particular the *Busseola fusca* (Fuller), *Sesamia calamistis* (Hampson), *Eldana saccharina* (Walker) and *Mussidia nigrivenella* (Ragonot) (Goergen *et al*., 2016). FAW has been reported to attack maize at all stages of the plant's growth. Despite the importance of QPM in cereal based staple foods, there was little or no updated information linking the FAW damage with the pest population density and growth stages of the maize crop on which high economic injury levels (EIL), caused by the pest may occur in the plant.

Economic injury level (EIL) is the lowest number of insects that will cause economic damage, or minimum number of insects that would reduce yield equal to gain threshold. EIL is really a level of injury, because injury is usually difficult to measure in a field situation, therefore number of insects is used as an index of that injury (Pedigo, 2004). The relationship between the EIL and ET demonstrates that action taken when population levels exceed the ET forces down the population before it reaches the EIL. Economic damage is the amount of injury which will justify the cost of artificial measures. Economic damage begins to occur when money required for suppressing insect injury is equal to potential monetary loss from a pest population (Pedigo, 2004). The work done on EIL of some crops in Nigeria reported that, EIL values of Cotton stainer (*Dysdercus volkeri*) on cotton in 2019 and 2020 cropping seasons were found to be 2.27 and 3.02 nymphs per plant, respectively, using Cypermethrin insecticide (Musa, 2021) whereas Memon *et al.* (2011) reported EIL of plant sucking bugs in cotton as 1.78 to 1.80 insects per plant. The EIL of *D. volkeri* on sunflower was found to be 2 to 3 bugs/ head which could consume enough plant tissue to reduce yield by 2 to 3 kg/ha (Mani, 2013). However, Adamu *et al*. (2006) found that the EIL of ovipositing and feeding adults of head bug *Eurystylus oldi* on sorghum was 0.08 and 5.92 using Cypermethrin respectively. Wazire and Patel (2016) showed that EIL differed across season, stage of crop development, cultivars and efficacy of insecticides used.

Therefore, the objective of this work was to determine the economic injury levels (EIL) of Fall Armyworm (*S. frugiperda* Smith) at the early-whorl vegetative growth stage of SAMMAZ 36 quality protein maize (QPM).

MATERIALS AND METHODS

Experimental Sites

The experiments were conducted at the screen-house of Department of Crop Protection, Ahmadu Bello University, Samaru (11^0 10′ N, 07^0 37′ E), Zaria in 2020 and 2021 (June-November) wet seasons.

Collection and Mass Rearing of Fall Armyworm Larvae

Fall Armyworm (FAW) larval colony used for the experiments was obtained from the insect rearing laboratory of Department of Crop Protection, Ahmadu Bello University, Zaria where they were reared on artificial diet as described according to Centre for Maize and Wheat Improvement (CIMMYT) adapted from Tefera *et al*. (2011) protocol.

Preparation of One Litre Artificial Diet

Maize leaf powder (25.2g), cowpea powder (88.4g), brewer's yeast (27.7g), ascorbic acid (2.5g), sorbic acid (1.3g), multivitamin (2.1g) and sucrose (35.1g) were mixed properly using a clean plastic spoon in a clean plastic container. Distilled water was added, and the contents were thoroughly mixed using a blender for two minutes. Methyl-p-hydroxybenzoate was dissolved in 10 ml of 70% ethanol and added to the mixture and then blended for another two minutes. Using a separate plastic container, agar powder (25.3g) and distilled water (403.1ml) were mixed and blended for two minutes. The mixture was then boiled for three minutes while stirring periodically, and then allowed to cool to 60 ^{0}C. After cooling, it was added to the previous mixture in the first container, and both were blended thoroughly for three minutes. Finally, formaldehyde (2.0ml) was added to the mixture in the blender and then blended for three minutes. The diet was then dispensed into different plastic jars (Plate I).

Bulk Rearing of Fall Armyworm Larvae on Artificial Diet

Two hundred grams of the already prepared diet was poured into two different plastic jars (height: 16 cm, bottom diameter: 11 cm, top diameter: 10 cm). One hundred FAW neonate larvae were introduced into each plastic jar using camel hairbrush, then covered with tissue paper and tied with a cover lid. The plastic jars were placed in the laboratory table at room temperature (28 ± 2 °C) and relative humidity (70 ± 5%). The larvae were observed daily and viewed under hand lens (90 mm) for changes in development of the larval instars. When most of the larvae (50%) had attained second instar larval stage, they were sorted out and then used to infest SAMMAZ 36 QPM that was used for the experiments.

Plate I: Fall armyworm formulated diet

Screen-house Experiment

The experiment was conducted in pots (30 cm top diameter, 16 cm bottom diameter and 36 cm height) at the screen house of Department of Crop Protection, Ahmadu Bello University, Zaria during 2020 and 2021 wet seasons for a duration of five months (June – November). A quality protein maize variety (SAMMAZ 36) was artificially infested with different FAW larval densities (0, 2, 4 and 6) per plant at the early-whorl growth stage (two weeks after emergence) (Seshu-Reddy and Sum, 1991). Plants with 0 larva served as untreated control.

The treatments were repeated three times and laid out in a completely randomized design (CRD). Plastic pots (cone shape) were initially filled with 10 kg sterilized loamy soil. SAMMAZ 36 plants grown in different pots were sown at the rate of two seeds per pot and placed in separate wooden cages (having 2.0 m height, 1 m length and 0.5 m width) at the screen house. They were thinned to one seedling per stand two weeks after sowing. The cages including the bottom edges were designed in such a way that they did not interfere with ventilation of the growing plants within the cage. The second instar larvae of *S. frugiperda* were released using a camel hairbrush into the leaf whorl of each plant two weeks after emergence. Each treatment was harvested separately for evaluation at the end of the experiment which lasted for a period of five months.

Data Collection

Cob Damage Rating**:** Cob damage was rated at harvest based on modified Davis and Williams (1992) cob damage scale of 1-5 as presented in Table 1.

Grain Yield (kg/ha)**:** This was determined from the plant in each cage that was harvested and threshed. The grain was weighed in kg per pot (treatment) then extrapolated to kg ha^{-1}.

Table 1: Modified scale for assessment of cob damage due to fall armyworm in maize

Score/Rating	Damage symptoms/description	Response
1	No damage to the ear	Highly resistant
2	Damage to a few kernels (1-15) or less than 10 % damage to an ear	Resistant
3	Damage to 16-50 kernels or less than 25 % damage to an ear	Partially resistant
4	Damage to 51-100 kernels or more than 50 % but less than 60% damage to an ear	Susceptible
5	Damage to >100 kernels or 60 – 100 % damage to an ear	Highly susceptible

Source: Modified Davis and Williams (1992)

Yield Loss (%)

Percent yield loss was determined from the formula:

$$\text{Yield loss (\%)} = \frac{\text{(Yield of untreated control)} - \text{(Yield in respective treatments)}}{\text{Yield of untreated control}} \text{ x } 100$$

Economic Injury Level

The economic injury level (EIL) was computed by a formula below sourced from Pedigo (2004) and Adamu (2005):

$$\text{EIL} = \frac{\text{Gain threshold}}{\text{Yield reduction per larvae}}$$

Gain threshold (minimum economic damage) is the cost of insect management/ha per market value (price) of grain/kg.

$$\text{Gain threshold} = \frac{\text{Management cost ₦/ha}}{\text{Market value (price) of grain ₦/kg}}$$

For calculating management cost, the cost of the insecticide and number of insecticidal sprays including labour charges were considered. Belt Expert 480SC (Flubendiamide 240 g/l + Thiacloprid 240 g/l) at 150 ml/ha was considered for calculating the cost of insecticidal applications.

The monetary values of yield losses were determined according to the prevailing market price of maize grain/kg at Zaria just after harvest.

Data Analysis

Data obtained were subjected to analysis of variance (ANOVA) and the significant means were compared using Student Neuman Keuls (SNK). The analysis was carried out using Statistical Analysis System (SAS, 2003).

Relationship between the fall armyworm larval densities and the percent yield losses were determined by coefficient of determination (R^2) and regression equation: $Y = a + bx$ where: Y= expected yield per caged plant, a= intercept (constant representing the yield of un-infested plants), b = slope (yield loss per larvae) and x = number of larvae per caged plant.

RESULTS

The results in Table 2 show the effect of fall armyworm damage at early-whorl vegetative growth stage of SAMMAZ 36. In 2020, maize plants infested with different densities of fall armyworm (FAW) larvae at the early-whorl growth stage (V4) showed a consistent increasing trend in cob damage rating with increase in FAW larval densities. Cob damage rating at the early-whorl growth stage was higher with plants infested with 6 (3.33) FAW larval density, although it did not differ significantly from plants infested with 4 (2.67) larval densities.

Table 2: Effect of fall armyworm larval density at early-whorl vegetative growth stage (V4) of SAMMAZ 36 evaluated in the screen house at Samaru, Zaria, in 2020 and 2021

Larval density per plant	Cob damage rating		Grain yield (kg/ha)		Yield loss (%)	
	2020	2021	2020	2021	2020	2021
0	1.00c	1.00c	3715.50a	4088.79a	0.0c	0.0c
2	2.00b	2.33b	3377.69ab	3555.47ab	09.1bc	13.0b
4	2.67ab	2.33b	3022.15bc	3377.69ab	18.7ab	17.4ab
6	3.33a	3.33a	2666.60c	3022.15b	28.2a	26.1a
Mean	2.25	2.25	3195.49	3511.03	13.99	14.13
LSD	0.77	0.94	652.70	766.94	15.45	9.00
P-value	0.0028	0.0033	0.0291	0.0467	0.0150	0.001

Means followed by the same letter (s) in a column are not significantly different at $P \leq 0.05$

Plants with 0 larva of FAW had higher grain yield than those infested with 2, 4, and 6 larvae. There was no significant difference in grain yield of plants with 0 and 2 larvae but however, differed significantly from the grain yield of plants infested with 6 larval densities.

Plants with 0 larva had zero yield loss therefore, differed significantly from the reductions recorded for plants infested with 4 and 6 larvae but, was statistically similar with yield losses recorded for plants infested with 2 larvae. At 6 FAW larvae per plant, the pest population reduced yield by 28.2 %. The coefficient of determination between larval density and percent yield loss was strong and positive (R^2= 0.9037) at stage V4 (Figure 1).

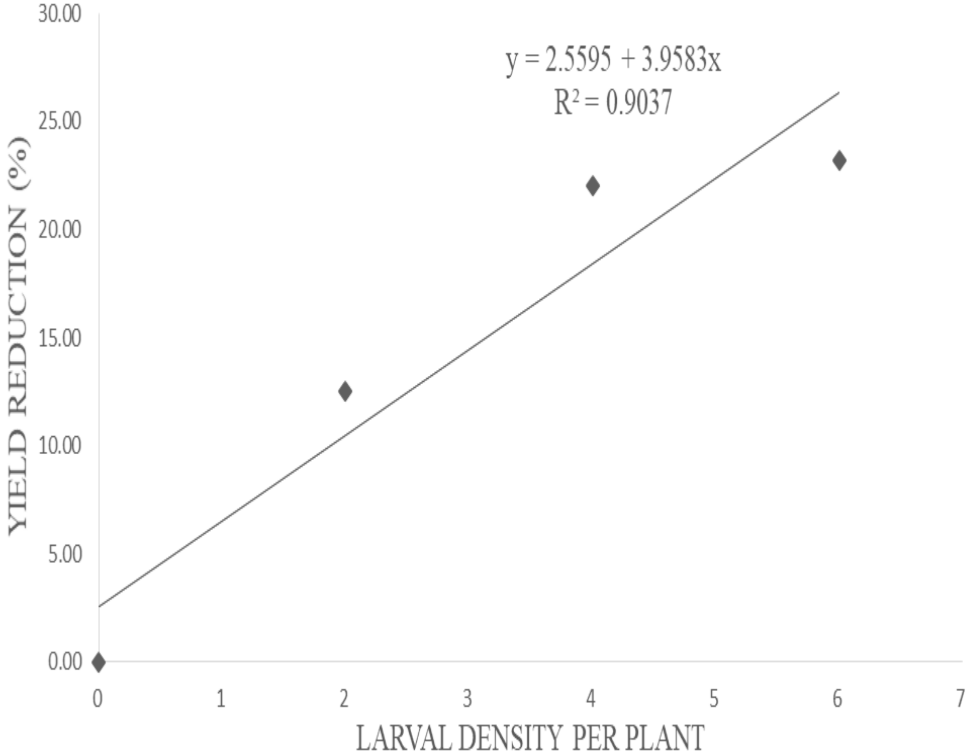

Fig 1: Relationship between fall armyworm larval density and percent yield loss at early-whorl (v4) growth stage of SAMMAZ 36 evaluated in the screen house at Samaru, Zaria in 2020

In 2021, plants with zero larva had lower cob damage rating which was significantly different (P≤0.05) from plants infested with 2, 4 and 6 FAW larval densities (Table 2). Similarly, plants infested with 2 and 4 larval densities had lower cob damage rating and differs significantly from plants infested with 6 larvae. Grain yield of plants with 0 larva was higher and differed significantly (P≤0.05) from the yield of plants infested with 6 larvae of FAW. Furthermore, plants infested with 0, 2 and 4 larval densities are statistically similar. Plants with 0 larva had zero yield loss and differed significantly from the reductions recorded for plants infested with 2, 4, and 6 larvae. There was a strong and positive relationship between larval density and percent yield loss (R^2 = 0.9646) at stage V4 (Figure 2).

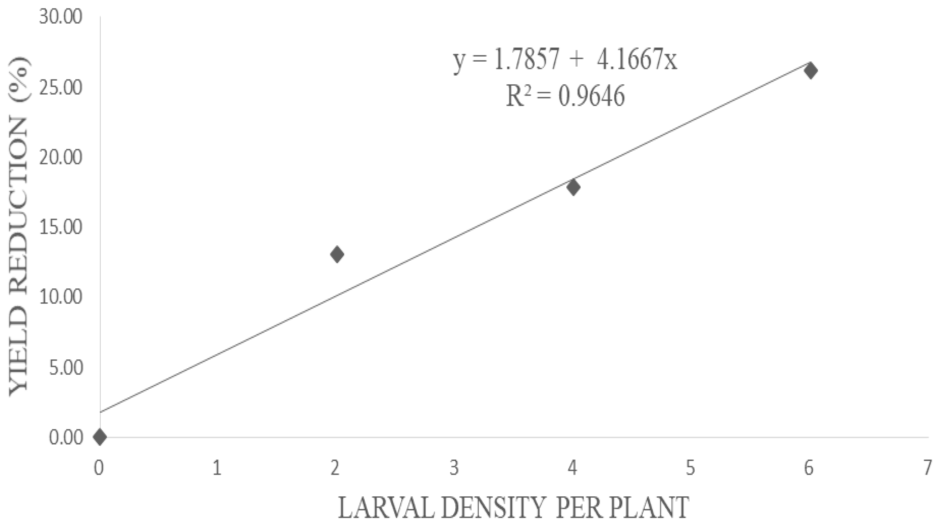

Fig 2: Relationship between fall armyworm larval density and percent yield loss at early-whorl (v4) growth stage of SAMMAZ 36 evaluated in the screen house at Samaru, Zaria in 2021

Economic Injury Levels of Fall Armyworm at Early-Whorl Growth Stage of SAMMAZ 36

To calculate the EIL, it was necessary to know not only the rate of yield reduction by fall armyworm larvae, but also the cost of controlling the insect and the prevailing market price of the crop. In calculating EIL of fall armyworm on SAMMAZ 36 quality protein maize, the following steps were followed:

1. Determination of management cost (cost of insecticide x number of insecticidal sprays + labour charges).

Cost of belt expert (BE) insecticide at the rate of 150 ml/ha (0.15 L) was ₦ 2,400 and ₦ 3,200 in 2020 and 2021 respectively (Table 3).

i. Cost of chemical (150 ml/ha) twice in 2020 = ₦ 2,400 x 2 = ₦ 4,800
ii. Cost of chemical (150 ml/ha) twice in 2021= ₦ 3,200 x 2 = ₦ 6,400
iii. Cost of application in 2020: Four labourers at ₦ 500 per labourer for the 2 applications = 4 x ₦500 x 2 = ₦ 4,000
iv. Cost of application in 2021: Four labourers at ₦ 500 per labourer for the 2 applications = 4 x ₦500 x 2 = ₦ 4,000

Management cost in 2020 (i and iii) = ₦ 4,800.00 + ₦4,000.00 = ₦ 8,800.00
Management cost in 2021 (ii and iv) = ₦ 6,400 + ₦ 4,000.00 = ₦ 10,400.00 (Table 3)

2. Determination of market price of maize per kg

In 2020, the market price of maize/kg was = ₦ 500/kg
In 2021, the market price of maize/kg was = ₦ 750/kg (Table 3)

3. Determination of gain threshold which is the amount of yield loss that constitutes economic damage. The following formula was used to calculate gain threshold:

$$\text{Gain threshold (kg/ha)} = \frac{\text{Management cost ₦/ha}}{\text{Market value (price) of grain ₦/kg}}$$

In 2020, $\frac{8{,}800\ \text{₦}/ha}{500\ \text{₦}/kg}$ = 17.60 kg/ha while in 2021, $\frac{10{,}400\ \text{₦}/ha}{750\ \text{₦}/kg}$ = 13.87 kg/ha (Table 3)

$$\text{EIL} = \frac{\text{Gain threshold}}{\text{Yield reduction per larvae}}$$

The EIL for a particular stage is the number of infesting fall armyworm larvae that would reduce the yield by 17.60 kg/ha. Since Y (y) = a + bx, it followed that bx = Y – a = - (a – y). But a – y is the reduction (intercept representing the yield of un-infested plant minus the expected yield per caged plants). Therefore, bx = 17.60 in 2020 while bx = 13.87 in 2021.

For 2020:

bx = y – a = - (a – y). Since bx = (3.9583) x = 17.60 where (3.9583 = y value from yield reduction regression equation (Fig 1) and 17.60 = gain threshold). Therefore, x = 17.60 ÷ 3.9583 = 4.44 ≈ 4.

For 2021:

bx = y – a = - (a – y). Since bx = (4.1667) x = 13.87 where (4.1667= y value from yield reduction regression equation (Fig 2) and 13.87 = gain threshold). Therefore x = 13.87 ÷ 4.1667= 3.32 ≈ 3.

Table 3: Economic injury levels of fall armyworm (*Spodoptera frugiperda*) on SAMMAZ 36 evaluated in the screen house at Samaru, Zaria in 2020 and 2021

Year	Insecticide type	Cost (₦)	Management cost (₦/ha)	Cost of maize (₦/kg)	Gain threshold (kg/ha)	EIL
2020	Belt Expert (Flubendiamide and Thiacloprid)	2,400.00	8,800.00	500.00	17.60	4.44
2021	Belt Expert (Flubendiamide and Thiacloprid)	3,200.00	10,400.00	750.00	13.87	3.32
Mean		2,800.00	9,600.00	625.00	15.74	3.88

DISCUSSION

Fall armyworms cause different levels of injury to plants depending on developmental stages of the plant and type of variety (Buntin, 1986). Highest cob damage rating (severity) in this study was observed on plants infested with six larval densities whereas highest grain yield was observed on plants with zero infestation, but plants infested with varying number of FAW larvae had significantly lower yields in both years. This observation agrees with the report by Rao *et al.* (2000) that the severity of damage inflicted by an arthropod pest on a crop is a function of the infestation density, feeding habits and oviposition characteristics of the species, as well as the host plant and its response to the activity of the pest. In the present study, plants infested with six larvae of FAW had the highest yield losses. Yield reductions in maize plant varied from 14.3 to 22.7% and younger plants at the early growth stage were preferred by FAW for oviposition, and those plants infested early in their development were less tolerant (susceptible) than plants infested later (Harrison, 1984). According to Williams and Davis (1990), infestation with 30 fall armyworm larvae per plant of a corn hybrid resulted in extensive leaf feeding damage and a 13% yield reduction. The percentage yield loss in this study increased with increase in larval density. There was linear relationship between *Chilo partellus* larval density and percent grain yield in maize and that percent yield loss in infested maize increases with increase in larval density of *C. partellus* with highest yield losses of 85.3 and 84.7% occurring when 9 larvae per plant were released compared to minimum of 3.5 and 1.3% in 1 larva per plant treatment during kharif and rabi seasons, respectively in India (Chouraddi and Mallapur, 2017). The findings of this study showed the coefficient of determination (R^2) to be high for both years, and this offered a more reliable explanation for the nature of the association. This also implied that FAW damage significantly influenced maize grain yield with the increasing number of FAW larvae. Regression between yield (kg/ha) and fall armyworm larval densities was negative and linear at the early-whorl growth stage. The linear relationship indicates a yield reduction proportionate to infestation levels and lack of compensation following the FAW attack. In the present study, the economic injury level values determined were 4.44 and 3.32 FAW larvae per plant in 2020 and 2021, respectively. Findings from different authors have reported that EIL values of cotton stainer (*Dysdercus volkeri*) on cotton in 2019 and 2020 cropping seasons were 2.27 and 3.02 nymphs per plant respectively, using Cypermethrin insecticide (Musa, 2021). However, Mani (2013) who worked on EIL of *D. volkeri* on sunflower reported that 2 to 3 bugs/ head could consume enough plant tissue to reduce yield by 2 to 3 kg/ha.

CONCLUSION

The economic injury level values determined from this study were 4.44 and 3.32 FAW larvae per plant in 2020 and 2021, respectively.

Based on these findings, when FAW densities of at least three larvae per plant are detected, control measures should be initiated to prevent FAW population build up and economic damage at the early-whorl (21- 28 days after emergence) vegetative growth stage of maize.

REFERENCES

Abrahams, P., Bateman, M., Beale, T., Clottey, V., Cock, M., Colmenarez, Y. and Godwin, J. (2017). *Fall Armyworm: Impacts and Implications for Africa*. Evidence Note (2). Retrieved from https: // www. Invasive-species .org /wp-content /uploads /sites /2/2019/ 02/FAW

Adamu, R.S. (2005). Studies on economic injury levels and control of *Eurystylus oldi* Poppius on sorghum (*Sorghum bicolor* (L.) Moench). Ph.D. thesis, Department of Crop Protection, Ahmadu Bello University, Zaria. 246pp.

Adamu, R.S., Onu, I. and Ogunlana, M.O. (2006). Economic injury levels of ovipositing and feeding adults of the headbug *Eurystalis oldi* pop. on *Sorghum biocolor* L. Moench. *Journal of Tropical Bioscience,* 6:50-54.

Assefa, F. and Ayalew, D. (2019) Status and control measures of fall armyworm (Spodoptera frugiperda) infestations in maize fields in Ethiopia: A review. *Cogent Food and Agriculture*, 5:1, doi: 10.1080/23311932.2019.1641902

Bjarnason, M. and Vasal, S.K. (1992). Breeding of quality protein maize (QPM). *In*: J. Janick (ed.), *Plant Breeding Reviews*, Vol 9. John Wiley and Sons, Inc., New York, United State of America.

Bressani, R. (1992). Nutritional value of high lysine maize in human. *In*: E.T. Mertz (ed). Quality protein maize. *American Association of Cereals Chemists*. St. Paul Minesota. U.S.A. 271 pp.

Buntin, G.D. (1986). A review of plant response to fall armyworm, *Spodoptera frugiperda* (J.E. Smith), injury in selected field and forage crops. *The Florida Entomologist*, 69: 549-559.

Chouraddi, M. and Mallapur, C.P. (2017). Assessment of crop loss and economic injury level of maize stemborer, *Chilo partellus* (Swinhoe). *Journal of Entomology and Zoology studies*, 5(4): 1530-1535.

Davis, F.M. and Williams, W.P. (1992). Visual rating scales for screening whorl-stage corn for resistance to fall armyworm. Mississippi Agricultural & Forestry Experimental Station, *Technical Bulletin 186, Mississippi State University*, MS39762, USA.

Goergen, G., Kumar, P.L., Sankung, S.B., Togola, A. and, Tamò, M. (2016). First report of outbreaks of the fall armyworm *Spodoptera frugiperda* (JE Smith) (Lepidoptera, Noctuidae), a New Alien Invasive Pest in West and Central Africa. *PLoS ONE*, 11(10):1-9.

Harrison, F.P. (1984). Fall armyworm symposium: Observations on the infestation of corn by fall armyworm (Lepidoptera: Noctuidae) with reference to plant maturity. *Florida Entomologist* 67(3): 333-339.

IAR (2021). Crop Variety Descriptors. A Compendium of Crop Varieties bred and Released by the Institute for Agricultural Research. Institute for Agricultural Research, Federal Ministry of Agriculture and Rural Development, Ahmadu Bello University, Zaria, Nigeria. 32pp.

IAR (2022). Institute for Agricultural Research 2019/2020 Annual Report. Ahmadu Bello University, Zaria, Nigeria. 52pp

IITA (2016). First report of outbreaks of the “Fall Armyworm” on the African continent. Bulletin no. 2330. Retrieved from http://bulletin.iita.org/index.php/2016/06/18/ first-report of -outbreaks -of- the fall armyworm-on-the-african-continent/ International Institute of Tropical Agriculture.

Kamara A.Y., Kamai, N., Omoigui, L.O., Togola, A., Ekeleme, F. and Onyibe, J.E. (2020). Guide to maize production in northern Nigeria: lbadan, Nigeria. Unpublished report. 18pp.

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, 103-111.

Macauley, H. (2015). Cereal crops: rice, maize, millet, sorghum, wheat: background paper. Conference on ‘Feeding Africa’ Dakar, Senegal, 21–23 October 2015. https://www.afdb.org/fileadmin/uploads/afdb/Documents/Events/DakAgri2015/Cereal_ Crops-_Rice__ Maize__Millet__Sorghum__Wheat.pdf (Accessed 5 October 2017).

Mani, U. (2013). Bioecology and Economic Injury Levels (EIL) of *Dysdercus volkeri* F (Heteroptera: Pyrrhocoridae) on Sunflower *(Helianthus Annuus* L.) in Samaru Zaria, Nigeria. Ph.D. Thesis, Department of Crop Protection, Ahmadu Bello University Zaria Nigeria, 87 pp

Memon, S.A., Rustamani, M.A., Sahito, H.A., Narejo, M. Mal, B. and Mahesar, T.G. (2011). Effect of agrochemicals on sucking insect pests of cotton crop. *Life Science International Journal*, 5(3): 2280-2287.

Nurit, E. and Palacios-Rojas, N. (2006). Tryptophan determination in maize grain using glyoxylic acid. Unpublished report. 5 pp.

Musa, N. (2021). Bioecology and Economic Injury Level (EIL) of *Dysdercus volkeri* f. (Heteroptera: Pyrrhocoridae) on cotton (*Gossypium hirsatum* (l.) varieties in northwestern Nigeria. Ph.D. thesis, Department of Crop Protection, Ahmadu Bello University, Zaria. 194 pp.

Pedigo, L.P. (2004). *Entomology and Pest Management*. Fourth Edition. Prentice- Hall of India Private Limited New Delhi. 742pp.

Pogue, M.G. (2002). A world revision of the genus *Spodoptera guenée:* (Lepidoptera: Noctuidae). *American Entomological Society* Philadelphia. Retrieved https://www.ars.usda.gov/research/ publications/publication/?seqNo115=110657

Prasanna, B., Huesing, J., Eddy, R. and Peschke, V. (2018). *Fall Armyworm in Africa: A guide for Integrated Pest Management*. 1st Edition.; Mexico, CIMMYT.

Rao, M.R., Singh, M.P. and Day, R. (2000). Insect pest problems in tropical agro-forestry systems: Contributory factors and strategies for management. *Agroforestry Systems* 50: 243-277.

Roger, D.A., Melanie, B.P., Tim, B., Victor, C., Matthew, C. and Yelitza, C. (2017). Fall armyworm: Impacts and implications for Africa. *Outlooks on Pest Management*. 28(5):196– 201.

SAS (2003). SAS Institute, SAS/STAT. Users Guide version 6, Fourth Edition, volume 2 SAS Institute Cary, N.C.66 pp.

Seshu Reddy, K.V and Sum, K.O.S. (1991). Determination of economic injury level of the stem borer *Chilo partellus* (Swinhoe) in maize, *Zea mays* L. *Insect Science and its Application*. 12 (1, 2 & 3): 269-271.

Sisay, B. (2018). Evaluation of different management options of fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) and assessment of its parasitoids in some parts of Ethiopia. *M.Sc. Thesis*, 56 pp.

Tefera, T., Mugo, S., Tende, R. and Likhayo, P. (2011). Methods of screening maize for resistance to stem borers and post-harvest insect pests. *International Maize and Wheat Improvement Center (CIMMYT), Nairobi, Kenya*.

Tufa, B. and Ketema, H. (2016). Effects of different termite management practices on maize production in Assosa district, Benishangul Gumuz Region, Western Ethiopia. *Journal of Biology, Agriculture and Health care*, 6(26): 27–33.

Usman, M.S. (2014). Effect of *Sitophilus zeamais* (Motsch.) infestation on protein contents of stored grains of quality protein maize varieties. M.Sc. Thesis, Department of Crop Protection, Ahmadu Bello University, Zaria. 105pp.

Wazire, N. S. and Patel, J. I. (2016). Determination of economic injury level (EIL) for leaf webber and capsule borer, *A. catalaunalis* (Duponchel) in sesamum. *International Journal for Life Science*,169-172.

Williams, W.P. and Davis, F.M. (1990). Response of corn to artificial infestation with fall armyworm and southwestern corn borer larvae. *Southwestern Entomologist,* 15(2): 163-166.