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Research Article

Efficacy of Insecticidal Net in Controlling Fall Armyworm (*Spodoptera frugiperda*) Population and Damage on Maize (*Zea mays* L.) in Sierra Leone

Alusaine Edward Samura[1], Vandi Amara[1,*], Raymonda Johnson[1,2], Dan David Quee[1], Musa Decius Saffa[1], Macro David Tarawally[1], Kevin Barry Rice[3], Alieu Mohamed Bah[4]

[1]Department of Crop Protection, Njala University, Njala Campus, Sierra Leone
[2]Ministry of Agriculture and Food Security, Freetown, Sierra Leone
[3]Division of Plant Science, University of Missouri, Missouri, USA
[4]Department of Crop Science, Njala University, Njala Campus, Sierra Leone

Abstract

The fall armyworm (*Spodoptera frugiperda*), a devastating pest of maize (*Zea mays*), poses a significant threat to maize production and food security in Sierra Leone due to its high reproduction rate and voracious feeding habits. This study evaluates the efficacy of insecticidal nets in controlling fall armyworm populations and minimizing damage to maize crops. A field experiment evaluated the efficacy of treated net in controlling fall armyworm (FAW) *Spodoptera frugiperda* and preventing it from causing economic damage to maize production. The experiment was a single factor in a randomized complete block design (RCBD) with three replications. There were four treatments comprising of an insecticidal net at different length (21 m, 13 m, and 8 m) and no net (Control). Each length of the net was assigned to one plot. The findings showed that a 21 m length insecticidal net recorded significantly, the highest plant height, number of leaves, 1000 grain weight, reduced fall armyworm egg masses, larvae, damaged leaves, cobs per plant, decreased FAW severity and natural enemies, increased number of adult moth death of fall armyworm. Whereas the untreated farms (control) revealed the lowest concerning parameters mentioned above, except for the number of infested plant leaves, number of egg masses and larvae per plant, and severity rates of FAW. There was a positive correlation between the number of adult death moths of fall armyworm and severity, number of larvae, egg mass, infected plants, infected cob and yield, and several natural enemies of fall armyworm in all the targeted farms. Thus, a 21 m length insecticidal net is recommended as the most efficacious treatment in maize production for resource-poor farmers.

Keywords

Insecticidal Net, Egg Masses, Larvae, Fall Armyworm, Maize, Yield

*Corresponding author: vandiamara66@gmail.com (Vandi Amara)

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1. Introduction

Maize (*Zea mays* L.) is the most extensively grown staple food crop in sub-Saharan Africa (SSA), covering 36 million hectares, and providing food and livelihood for about 208 million people in the region, where the surface area of cultivation stands at 36 million hectares [1, 2]. Maize is known to sustain the capacity to reduce food insecurity and improve the living standards. It is currently used as human diet, animal feed, biofuel, construction and renewable energy which help to mitigate climate change effect, thereby increasing crop productions [3].

Fall armyworm (*Spodoptera frugiperda*) belonging to the family Noctuidae, is a polyphagous indigenous pest which is native to tropical and subtropical regions of the Americas, where it has more than 350 different host plants including both crop and non-crop specie [4, 5]. Despite its ability to survive in different host plants, fall armyworm (FAW) is known to have a high preference for maize [6]. In Africa, FAW was first reported in West and Central Africa in 2016 [7] and rapidly spread to the rest of the continent with devastating consequences on maize production [8].

Unfortunately, the outbreak of fall armyworm (*S. frugiperda*) in Africa is causing significant damage to maize crops, thereby threatening the livelihood of numerous farmers who rely on maize production for income and food security [9-11]. In its native range, FAW is known to feed on over 350 plant species [5] but considering just maize, rice, sorghum and sugarcane it has been calculated that FAW could cause up to $US13 billion per annum in crop losses across sub-Saharan Africa [10]. It destroys young maize plants by attacking their growing points, and burrows into cobs in older plants, thereby adversely affecting the yield quantity and quality [12].

Consequently, considering that the pest cannot be eradicated, Various strategies have been recommended for managing FAW, including cultural, biological, chemical and botanical pesticides, genetically modified crops, agronomic practices, insecticides net and pheromone traps and integrated pest management [10]. Furthermore, most of the natural enemies of FAW reported on the continent are parasitoids, which are mainly Dipterans and Hymenopterans found on either eggs, larvae, or pupae of the pest [13-16]. Against this backdrop, the present research aims to assess the efficacy of insecticidal net in reducing fall armyworm population, damage, growth, and yield of maize.

2. Materials and Methods

2.1. Description of the Experimental Sites

The experiment was conducted in four villages (Mokonde, Bonganema, Foya and pelewahun) during the period July to October 2021. The geographical locations where the farms were established was 08.060 N and 12.060 W with an elevation of 5 m above mean sea level. The main vegetation of the study area was secondary bush with a well drainage depressions, undulating grasslands and low upland. The climate of the areas is tropical, characterized by a wet season (May to September) and dry season (October to April). The mean annual rainfall was 2800 mm; mean monthly temperature range from 33 ℃ to 28 ℃ and relative humidity of 70% was observed during the experimental period. The soil texture of the trial farms was gravely clay loam soil and its chemical properties (0-15 cm depth) were pH = 3.91, organic carbon = 1.85%, available P = 8.56 mg/kg, Total % of Nitrogen = 0.08% and K = 0.14 cmol/kg.

2.2. Research Material

Materials used for the implementation of this study were insecticidal nets and lures obtained from the Crop Protection Unit, Ministry of Agriculture and Forestry, Sierra Leone, pencils, permanent markers, black and white paints for farm labelling, measuring tape/ruler, and field notebook.

2.3. Experimental Design and Agronomic Practices

The experiment was a single factor, laid out in completely randomize design with three replications. The treatments comprised of three different lengths of insecticidal net (21 m, 13 m and 8 m respectively) and control farm where no insecticidal net was placed. In ach plot lures were applied to the net depending on the length of the net. Three lures (3) were applied to the 21 m length insecticidal net, two (2) lures to the 13 m length and one (1) lure to the 8 m length of the insecticidal net and each of the lures were placed 7 m apart. The purpose of the lure was to attract fall armyworm moths so that the net would kill them since the lure is a species specific. The experimental field was manually ploughed and levelled using hoe, demarcated to a plot size of 6.5 m x 4 m, with 1 m between replications and 0.5 m within plots given an area of 21.5 m × 17.5 m (0.04 ha). An improved maize variety 'Downy Mildew Resistance and Early Streak Resistance' yellow (DMR/ESR yellow) was sown at an inter and intra-row spacing of 75 x 50 cm respectively on the 6.5 x 4 m^2 plots, given a plant population of 23,333 plants ha^{-1}. Three seeds were sown and thinned to two 14 days after sowing prior to the application of N-P-K (15: 15: 15) fertilizer at the rate of 200 kg ha^{-1} using side placement method, while 60 kg N ha^{-1} of urea (46% N) was top dressed at active growth and tassel stages six weeks after planting (6 WAP) of maize.

2.4. Data Collection Procedure and Measurement Taken

Data were collected from ten randomly selected plants from the two central rows from the start of the net to end of the net placed to determine the following: Plant height (cm), number of leaves plant^{-1}, number of infested leaves plant^{-1}, number of egg mass plant^{-1}, number of fall armyworm larva plant^{-1}, number of damaged cobs plant^{-1}, severity rate plant^{-1}, number of natural enemies plant^{-1}, 1000 grain weight g^{-1} and grain yield t ha^{-1}.

Plants height was measured from 10 randomly selected hills (each containing two plants of the middle rows in the area where the nets were placed. Measurement was taken from the base of the stem up to the last emerged leaf using a graduated pole. The mean height from the 10 randomly selected hills at 3, 5 and 7 WAP was taken as the score for each plot. Number of leaves was determined by counting number of leaves from the 10 randomly selected hills and mean also calculated. Ten plants within the area where the nets were placed were randomly selected and visually evaluated to determine the total number of plants infested. Counts were performed at 3, 5 and 7 weeks after planting (WAP). The egg mass of fall armyworm counts was performed in the morning at 3, 5 and 7 weeks after planting. Number of Fall armyworm larva were counted at 3, 5 and 7 weeks after planting (WAP). The numbers of damaged cobs per plant were also recorded.

The severity was also scored using a scale of 1-5 (1=No symptoms, 2= Low, 3=Moderate, 4= High, 5=Very high). (David Salmon, Penny Powdrill 2012). One thousand maize grains were counted from the bulk of grains from the plants within area where the net covered, and their weights recorded.

At full maturity, the grain yield was determined from the 10 tagged plants within the area where the net was placed. The grain yield (t ha^{-1}) obtained was weighed after properly dried under the sun and grain yield converted to tones ha^{-1} using the formula reported by Ullah (2008).

2.5. Data Analysis

Data collected were subjected to analysis of variance using the PROC GLM procedure of Statistical Analysis System (SAS) computer software program, version 9.4 and Least Significant Difference (LSD) test was used to compare treatment means at 5% level of probability.

3. Results

3.1. Growth Response to Insecticidal Net Treatments

A one-way analysis of variance was performed on the data set in Table 1 to ascertain whether differences existed among percentages determined for the total germination of maize. The F-test performed showed significant differences ($P \leq 0.05$) among different lengths of insecticidal nets and the control treatment. The plant heights observed in 3, 5 and 7 weeks after planting (WAP) showed that there was a significant difference between ($P \geq 0.05$) farms where the insecticidal net was placed and controlled. There was a large variation in plant height between treatments (length of the insecticidal net). The highest height was significantly ($P \geq 0.05$) obtained from the fully protected treatment, which received 21 m length insecticidal net at 3, 5 and 7 WAP (25.7 cm, 87.4 cm and 135.6 cm), respectively. This was closely followed by 13 m length insecticidal net, which showed significant difference ($P \geq 0.05$) compared to 8 m length insecticidal net and control treatments. However, the lowest plant heights were obtained from farms that received none or no insecticidal net 16.6 cm (3 WAP), 48.1 cm (5 WAP) and 99.8 cm (7 WAP), respectively. Farms treated with 21 m length of the insecticidal net produced a maximum number of leaves (5.0, 9.5 and 13.5 plant^{-1}) followed by 13 m length (4.1, 7.0 10.6 plant^{-1}), and was significantly different ($P \leq 0.05$) from those other treatments at all sampling periods. The significant increase of leaf number in the insecticidal net treatment over control could imply that the net constitutes a lower density of FAW larvae which does greater destruction on maize. However, the control plots obtained significantly ($P \geq 0.05$) the lowest number of leaves per plant at 3 WAP (9.66 plant^{-1}), 5 WAP (16.66 plant^{-1}) and 7 WAP (23.33 plant^{-1}), respectively.

The statistical analyses indicated significant differences ($P \leq 0.05$) in the number of infested maize leaves per plant, induced by insecticidal net lengths and weeks after planting. The number of infested leaves per plant was, in general, significantly ($P \leq 0.05$) higher in control farms compared to other treatments at various assessment periods 3 (17.3 plant^{-1}), 5 (27.3 plant^{-1}) and 7 (35.0 plant^{-1}) weeks after planting. The lowest number of infested plant leaves were achieved with 21 meters length of insecticidal net at various periods of assessment, 3 WAP (2.0 plant^{-1}), 5 WAP (4.6 plant^{-1}) and 7 WAP (6.6 plant^{-1}).

Table 1. Effect of growth response to FAW at different maize growth stages during 2021 main cropping season.

Insecticidal net (m)	Plant height (cm)			Number of leaves plant^{-1}			Number of infested plant^{-1}		
	3 WAP	5 WAP	7 WAP	3 WAP	5 WAP	7 WAP	3 WAP	5 WAP	7 WAP
21 meters	25.7^{a}	87.4^{a}	135.36^{a}	5.0^{a}	9.5^{a}	13.5^{a}	3.00^{c}	4.6^{d}	6.6^{c}
13 meters	20.6^{b}	74.6^{b}	120.76^{ab}	4.5^{b}	7.0^{b}	10.6^{b}	9.00^{b}	13.6^{c}	20.3^{b}

Insecticidal net (m)	Plant height (cm)			Number of leaves plant^{-1}			Number of infested plant^{-1}		
	3 WAP	5 WAP	7 WAP	3 WAP	5 WAP	7 WAP	3 WAP	5 WAP	7 WAP
8 meters	18.3^{c}	60.83^{c}	109.40^{bc}	4.3^{c}	5.0^{c}	7.0^{c}	11.6^{b}	18.6^{b}	25.3^{b}
Control	16.6^{d}	48.1^{d}	99.86^{c}	3.6^{d}	3.0^{d}	3.3^{d}	17.33^{a}	27.3^{a}	35.0^{a}
Pr > F	<.0001	0.0002	0.0230	<.0001	<.0001	<.0001	0.0002	<.0001	<.0001
LsD	8.85	10.12	20.21	6.92	6.00	7.98	3.44	3.86	5.33
CV (%)	5.6	5.1	8.6	13.4	9.0	9.4	17.2	12.0	12.2

Means with the same letter are not significantly different.

3.2. Effects of Insecticidal Net on the Population and Damage of FAW

The statistical analyses indicated significant differences ($P \leq 0.05$) in the average number of fall armyworm (*S. frugiperda*) egg masses and larvae per plant at 3, 5 and 7 weeks after planting (WAP) respectively (Table 2). In general, the use of an insecticidal net significantly reduced the number of fall armyworm larvae per maize plant. During this study, the number of larvae was significantly higher in the untreated control farms compared to other farms where insecticidal nets were placed from 3 (11.6 plant^{-1}), 5 (21.6 plant^{-1}) and 7 (27.6 plant^{-1}) weeks after planting respectively. The average number of larvae per plant recorded with 21 meters length of insecticidal net was however the lowest at 3 (0.3 plant^{-1}), 5 (1.6 plant^{-1}) and 7 (2.3 plant^{-1}) weeks after planting, respectively. Similarly, the average number of egg masses counted per plant with the control farm (where the insecticidal net was not placed) was significantly higher at 3, 5 and 7 WAP (17.3, 26.6 and 37.6 plant^{-1}), respectively. However, the lowest overall average numbers of FAW egg mass per plant were obtained with 21 m length insecticidal net treatment followed by 13 m length insecticidal net respectively at various evaluation periods (3, 5 and 7 WAP).

Table 2. *Effect of insecticidal net on FAW egg masses and larva in maize production during 2021 main cropping season.*

Insecticidal net (m)	Number of egg masses plant^{-1}			Number of larvae plant^{-1}		
	3 WAP	5 WAP	7 WAP	3 WAP	5 WAP	7 WAP
21 metres	1.0^{d}	2.3^{d}	3.3^{c}	0.3^{d}	1.6^{c}	2.3^{d}
13 metres	4.3^{c}	10.6^{c}	19.3^{b}	2.6^{c}	7.3^{bc}	14.3^{c}
8 metres	8.6^{b}	20.0^{b}	25.0^{b}	6.0^{b}	13.6^{b}	21.6^{b}
Control	17.3^{a}	26.6^{a}	37.6^{a}	11.6^{a}	21.6^{a}	27.6^{a}
Pr > F	<.0001	0.0003	<.0001	<.0001	0.0012	<.0001
LsD	1.59	6.25	6.59	2.20	6.34	4.40
CV (%)	10.2	20.9	15.4	21.3	28.6	13.3

Means with the same letter are not significantly different

Severity of fall armyworm larvae on maize was statistically significant ($P \leq 0.05$) between the various treatments (Table 3). The severity was significantly higher in the untreated control plots compared to other plots where insecticidal nets were placed from 3 (3.0), 5 (4.0) and 7 (5.0) weeks after planting respectively. However, the severity rate of FAW in the 21 m length insecticidal net was significantly low at 3(1.1), 5(1.3) and 7(1.4) compared to 13 m at 3(1.8), 5(2.3) and 7(2.5).

The number of adult moth death of fall armyworm on maize farms was statistically significant ($P \leq 0.05$) between the various lengths of the insecticidal nets and control (Table 3). There was no (0.0) death of adult moth of fall armyworm recorded in control plots where the insecticidal nets were not placed (control farms). The highest number of adult death moth was recorded in farm treated with 21 m length at 3 WAP (6.0), 5 WAP (8.0) and 7 WAP (6.0) followed by 13 m at 3 WAP (3.1), 5 WAP (6.4), 7 WAP (5.1) and 8 m length of insecticidial net at 3(1.2), 5(4.4) and 7(4.3) weeks after planting (WAP) respectively.

Table 3. Effect of insecticidal net on FAW Severity and moth death in maize production during 2021 main cropping season.

Insecticidal net (m)	Severity score			Number of molt death plant^{-1}		
	3 WAP	5 WAP	7 WAP	3 WAP	5 WAP	7 WAP
21 meters	1.1^{c}	1.3^{d}	1.4^{d}	6.0^{a}	8.0^{a}	6.0^{a}
13 meters	1.8^{b}	2.3^{c}	2.5^{c}	3.1^{b}	6.4^{b}	5.1^{ab}
8 meters	2.3^{ab}	3.0^{b}	3.6^{b}	1.2^{c}	4.4^{c}	4.3^{b}
Control	3.0^{a}	4.0^{a}	5.0^{a}	0.0^{d}	0.0^{d}	0.0^{c}
Pr > F	0.05	0.003	<.001	<.001	0.012	<.001
LsD	1.5	2.2	2.5	2.20	3.34	2.40
CV (%)	10.2	20.9	15.4	21.3	28.6	13.3

Means with the same letter are not significantly different.

3.3. Effects of Insecticidal Net Treatment on the Yield of Maize

A one-way analysis of variance showed significant (P ≤ 0.05) effect for cob damage (Table 4). Cob damage was higher in control farms (17.33 plant^{-1}) followed by 6 m length insecticidal net (11.33 plant^{-1}) than in the other farms where the insecticidal nets were placed. The effect of insecticidal net length was statistically significant (P ≤ 0.05) with regards to 1000 maize grain weight. There was significant effect when insecticidal nets and control treatments data were analyzed for grain yield. Among the treatments, 21 m length insecticidal net had the highest yield (4.2 t/ha) followed by 13 m length insecticidal net (2.5 t/ha) while the untreated plot (Control) had the lowest yield (0.5 t/ha). The 21 m length of insecticidal net recorded superior grain weight (318.33 g) followed by 13 m (274.15 g), while the untreated farms (farms where insecticidal net were not placed) recorded the least hundred-grain weight (106.05 g). This could be attributed to significant increase in grain weight by 51.43% and 39.10%, respectively, as compared to the control treatment. In contrast, cob damage was significantly different (P ≤ 0.05) and showed lower damage with 21 m length insecticidal net (4.00 plant^{-1}).

Table 4. Effect of FAW on yield attributes and damage of maize cobs during 2021 main cropping season.

Insecticidal net (m)	Yield (t/ha)	1000 grain weight (g)	Number of damaged cobs plant^{-1}
21 metres	4.2^{a}	318.33^{a}	4.00^{c}
13 metres	2.5b	274.15^{b}	7.66^{bc}
8 metres	1.7^{c}	238.89^{bc}	11.33^{b}
Control	0.5^{d}	106.05^{c}	17.33^{a}
Pr > F	0.0002	0.0013	0.0034
LsD	38.66	36.04	5.08
CV (%)	8.2	11.3	25.2

Means with the same letter are not significantly different

The correlation analysis in Table 5 showed that there was a positive relationship (r = 0.42) between a number of fall armyworm adult moth deaths and the severity although not very strong. There was also a very strong positive relationship between the number of adult moth deaths and the number of larvae (r = 0.72) and the number of egg mass (r = 0.50) in the farm thus indicating the higher the death of adult moths, the lower the number of larvae and egg mass present in the farm. The analysis further showed that positive correlation (r = 0.21) although weak exist between the number of adult moth death and number of infected plants and a strong correlation also exists between the number of adult moths and the number of infected cobs (0.50) which clearly indicated that higher death of adult moth resulted into lower number of infected plants and number of infected cobs. There was a positive correlation (r = 0.47) between the number of adult moth deaths and the yield of maize on the far.

Table 5. *Pearson correlation analysis between the number of deaths adult moth and severity, number larvae, egg mass, infected plant, infected cob and yield.*

Parameters	Number of adult moth death (r)
Severity	0.42
Number of larvae	0.71
Number egg mass	0.50
Infested plants	0.21
Number of infected cobs	0.50
Yield	0.47

4. Discussion

The plant heights observed at 3, 5, and 7 weeks after planting (WAP) varied significantly between farms where insecticidal nets were placed and the control, with the highest heights recorded in plots with 21 meters of netting. Additionally, the number of leaves per plant was significantly higher in plots with insecticidal nets, indicating potential protection against FAW larvae, which inflict substantial damage on maize. The number of infested leaves per plant respectively increased over time in farms treated with 21 m, 13 m and 8 m lengths of insecticidal nets, likewise with the control treatment. Overall, the average numbers of infested leaves per plant recorded with 13 m and 8 m insecticidal net lengths were not significantly different at 3 and 7 weeks after planting. The higher incidence of leaf damage could be due to failure to distinguish between leaf damage caused by FAW and other insect species. The present study results confirmed previous research done by Lima *et al*. [17], Hardke *et al*. [18], Kuate *et al*. [19] and Day *et al*. [20] who reported that FAW infests maize during all plant growth stages, especially during vegetative stages leading to serious leaf-feeding injury and defoliation. Thus, damage results in both quantitative and qualitative losses. The presence of insecticidal nets also resulted in significantly lower levels of FAW infestation, with fewer larvae and egg masses observed compared to control plots, particularly with the 21-meter netting treatment. Similarly, the severity of FAW damage was significantly reduced in plots with insecticidal nets, further indicating the efficacy of this pest management strategy. The high severity rate obtained with untreated indicates that high levels of damage was caused by FAW with regards to infested leaves and number of cobs damaged, which is almost in the same range with what has been reported by previous studies in Ethiopia, Kenya and Zimbabwe [21, 22]. Adult moth mortality was also significantly higher in plots with insecticidal nets, particularly with the 21-meter treatment, suggesting effective control of FAW populations. The high severity of the FAW is like what has been reported by Aguirre *et al*. [21] that cultivation throughout the year promotes population build-up, allowing several generations to overlap within a single crop cycle with suitable prevailing conditions responsible for the high severity rate observed in control and 8 m length insecticidal net treatments. The levels of FAW damage reported in this study, appears to be in the same range as previous studies and reports that estimated FAW damage in sub-Saharan Africa over the past two years [22]. Moreover, grain yield was significantly higher in plots with insecticidal nets, particularly with the 21-meter netting, while cob damage was significantly lower in these plots. These findings underscore the potential of insecticidal nets as an effective and sustainable strategy for mitigating FAW damage and improving maize productivity, with implications for pest management practices in agricultural systems. Additionally, correlations between various parameters such as adult moth mortality, severity of damage, and grain yield provide valuable insights into the interplay between pest control measures and crop performance, highlighting the importance of integrated pest management approaches for sustainable maize production.

5. Conclusion

Conclusively, the 21 m length insecticidal net recorded the highest plant height and number of leaves, lowest number of infested plant leaves, decreased number of egg masses and larvae per plant, reduced number of damaged cobs, superior 1000 grain weight, decreased FAW severity rate and natural enemies. Thus, indicating that it was more efficacious than the other treatments. While the control treatment revealed the lowest with parameters mentioned above except for number of infested plant leaves, number of egg masses and larvae per plant, and severity rates of FAW. Therefore, this study recommended that 21 m length insecticidal net control measure of FAW egg masses and larvae showed successful control method for resource poor maize farmer based on its influence on yield and therefore farmers should be encouraging to adopt it.

Abbreviations

FAW	Fall Arymyworm
RCBD	Randomized Complete Block Design
SSA	Sub-Sahara Africa
WAP	Weeks After Planting

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Author Contributions

Alusaine Edward Samura: Conceptualization, Investigation, Methodology, Validation, Formal analysis, Writing draft, Writing review and editing, Resources

Vandi Amara: Conceptualization, Investigation, Methodology, Validation, Formal analysis, Writing draft, Writing review and editing

Conflicts of Interest

The authors declare no conflicts of interest.

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