

Research Article

Evaluation of Systemic Insecticides and Application Frequencies Against Fall Armyworm (*Spodoptera Frugiperda*) on Maize (*Zea mays* L.) at Yabello and Abaya, Southern Ethiopia

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Abstract

Maize is a widely cultivated and economically important crop, serving as a major source of food and income for households in the study area. However, its productivity is severely constrained by both abiotic and biotic factors, among which fall armyworm (*Spodoptera frugiperda*) is the most destructive insect pest, causing significant yield losses. This study was conducted to evaluate and identify effective insecticides for the management of fall armyworm in maize. The experiment was carried out using three insecticides—Rambo 24.7% EC, Wantox 40% EC, and Con-Fidence 350 SC (*Imidacloprid* 35% W/V)—along with an untreated control, arranged in a randomized complete block design. The maize variety Melkasa-4 was planted at a spacing of 75 cm between rows and 25 cm between plants. Insecticides were applied after the onset of infestation, and pest incidence and damage levels were assessed over three consecutive spray rounds. Agronomic parameters, including plant height, number of cobs per plant, number of infected cobs, hundred-seed weight, grain yield, and flowering and maturity dates, were recorded. Data were analyzed using SAS software. The results showed that plots treated with Con-Fidence 350 SC (*Imidacloprid* 35% W/V) had the lowest fall armyworm infestation (16.44%), whereas the untreated control recorded the highest infestation (96.07%). Similarly, the highest grain yield (4250.38 kg/ha) was obtained from plots treated with Con-Fidence 350 SC, while the lowest yield (1126.0 kg/ha) was recorded in the control. Economic analysis revealed that this treatment also provided the highest net benefit (189,167.1 ETB) with an acceptable marginal rate of return. In conclusion, application of Con-Fidence 350 SC (*Imidacloprid* 35% W/V) at a rate of 0.4 L/ha was found to be effective in reducing fall armyworm infestation and improving maize yield. These findings provide a practical basis for improving the management of *Spodoptera frugiperda* and enhancing sustainable maize production in the study area.

Keywords

Maize, Fall Armyworm, Insecticides, Infestation, Grain Yield

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1. Introduction

Maize (*Zea mays* L.) is a major cereal crop cultivated worldwide and is increasingly favored by farmers due to its versatility and high productivity. Globally, it is grown on approximately 193.7 million hectares, with an average yield of about 5.75 tons per hectare [1]. Maize ranks alongside rice and wheat as a principal food crop and is widely used in diverse industrial applications [2]. It serves as a key raw material for products such as corn oil, margarine, corn syrup, sweeteners, marmalade, and instant non-dairy coffee creamer, in addition to its extensive use as animal feed [3]. Beyond its economic value, maize contributes significantly to food security and improved livelihoods. More recently, it has also been utilized in biofuel production, offering a renewable energy source that can help mitigate climate change impacts. Maize is a staple food for millions of people, particularly in Sub-Saharan Africa (SSA), where it is cultivated on about 36 million hectares [4]. In Ethiopia, cereal production and marketing constitute a vital component of the national economy [5]. In Ethiopia, maize is a strategic crop for food security. It ranks first in total production and productivity and second to teff in area coverage [6]. During the 2021/22 production year, maize was cultivated on approximately 2,563,201 hectares, yielding about 10,751,368.9 tons of grain, with an average productivity of 4.19 tons per hectare. However, in Borana, maize was grown on about 3,872.63 hectares, producing only 4,763.95 tons, with a much lower average yield of 1.2 tons per hectare [7]. This substantial yield gap between the national average and the study area is attributed to a combination of biotic and abiotic constraints. Among the biotic factors, fall armyworm (*Spodoptera frugiperda*) has emerged as one of the most destructive insect pests affecting maize in the field [8].

Fall armyworm is a highly polyphagous pest capable of feeding on more than 350 plant species, including maize, sorghum, rice, sugarcane, cabbage, groundnut, soybean, onion, cotton, and various grasses [9]. Despite its wide host range, maize remains its most preferred crop [10]. The larval stage is the most damaging, as larvae feed voraciously on plant tissues, often hiding in leaf whorls or soil during the day and emerging to feed primarily at night, although some populations may also feed during daylight hours. Infestations are often more severe following dry periods. If not effectively managed, fall armyworm can cause substantial yield losses. Estimates suggest global annual losses ranging from 8.3 to 20.6 million tons, equivalent to 21–53% of total maize production [11]. Other studies have reported yield losses of 11.6% [12], 32–47% [13], and up to 67% [11]. To mitigate the damage caused by fall armyworm, various management strategies can be employed. Among these, the use of effective insecticides remains one of the most immediate and practical approaches, providing rapid control of the pest, promoting healthy crop growth, and ensuring better grain quality. Therefore, this study was undertaken to identify the most effective insecticide for controlling fall armyworm in maize under the conditions of the study area.

2. Materials and Methods

Description of Study Area: The study was carried out during the main cropping seasons of 2024 and 2025 in the Yabello and Abaya districts. The Yabello district is found at 570km from the capital city Addis Ababa, to the southern part of the country with an altitude range of 1635masl and 04°51'1789"N, 038°06'223"E latitude and longitude respectively. Its soil feature is mostly known as sandy and has an annual maximum and minimum temperature of 26.3°C and 14.5°C respectively, with maximum and minimum annual rainfall of 700mm and 400mm. Abaya district is located 364km from Addis Ababa, and it is characterized by sandy loam soil. The area is located at an altitude range of 1442masl and latitude 06°43'520"N and longitude 038°25'425"E. The maximum and minimum temperature of the area is 29.9°C and 12.6°C respectively, while the average maximum and minimum rain fall is 1100 and 500mm.

Experimental Design and Materials: The experiment was done with four treatments arranged in randomized complete block design (RCBD) and it had three replications. The treatments were composed of three different commercial insecticides (Con-Fidence 350SC (*Imidacloprid* 35% W/V at 0.4litre/ha), Rambo 24.7% EC, and Wantox40% EC (Dime-thoate 40% at 900ml/ha)) and one control (unsprayed). It was sown with the space between rows and plant used 0.75m*0.25m respectively. Melkasa-4 variety was used to facilitate the application of the experiment. The insecticides were applied on three different applying dates with the intervals of seven days after the first occurrence of the insects on the crop. The spray was done with the help of a 15L capacity Knapsack sprayer.

3. Data Collected

Fall Armyworm Infestation and Damage score: Percent plant infestation: The experimental plot was monitored on a regular basis to document fall armyworm infestation, with a focus on damage caused by fall armyworm (*S. frugiperda*). Throughout the growth season, infestations were detected. The proportion of infested plants in each plot was scored 7–14 days following insecticide application. The first spray was sprayed at appearance of fall armyworm, followed by two sprays at 14-day intervals. Following each spray, observations on different variables, such as percent plant infestation, leaf and whorl damage, were recorded. The extent of infestation was determined using the formula suggested by [14].

Percent Infestation (%) = $\frac{\text{Number of Infested Plants in each Plot} \times 100}{\text{Total Number of Plants per Plot}}$

Damage score: Leaf and whorl damage caused by Fall Armyworm (*S. frugiperda*) was evaluated using a standardized visual rating scale ranging from 0 to 5, adopted by [15]. The crop foliar damage symptom was scored with the help of a 0-5 fall armyworm damage scoring scale. The scale description were 0- No visible symptoms on upper leaves and whorl,

1- Papery window damage symptoms on upper leaves and whorl, 2-Few small holes on upper leaves and whorl, 3- Raged holes on upper leaves and partially whorl, 4- Whorl and upper leaves extensively damaged and 5- Whorl completely destroyed and plant drying due to extreme defoliation [15]. The damage score and percentage were scored after the first, second and third spray of the insecticides. The crop flowering date (50% of plants per plot were flowered), maturity date (90% of the plants per plot were physiologically matured), stand count per plot, plant height from the ground to the top of the plant during harvest in centimeters, number of cobs per plant, number of damaged cobs per plant, a hundred seed weight, and grain yield per hectare in kilogram were scored. The grain yield (kg) was recorded from each net plot area after the harvested crop was threshed, and a hundred seeds were counted from each treatment and its weight was measured. Relative yield loss was calculated by using the following formula:

Relative Yield Loss (RYL%) = $\frac{\text{Maximum yield from treatment} - \text{Yield from a particular treatment}}{\text{Maximum yield from treatment}} \times 100$

Partial Budget Analysis: The partial budget analysis as described by [16] was performed to determine the economic feasibility of the insecticides against fall armyworm in maize. It was calculated by taking into account the variable input cost involved, and the gross returns obtained from different treatments. The marginal rate of return (MRR) was calculated as the change in net revenue (NR) divided by the change in total variable cost (TVC) of the successive treatments [16]. To decide the effectiveness of insecticide on fall armyworm management, it is important to consider both efficiency and cost.

Statistical Analysis: The collected data were subjected to analysis of variance using SAS software program version 9.3. Least significant difference (LSD) test at 5% probability level was employed to separate treatment means whenever a significant treatment difference exists. A Pearson correlation analysis was conducted to examine the relationship between grain yield and damage caused by the fall armyworm.

4. Result and Discussion

4.1. Mean Square Analysis of Fall Armyworm Infestation and Damage in Maize Across Three Spray Periods

The result from the scored data revealed that there was highly significant ($P < 0.001$) crop damage caused by fall armyworm (Table 1). Among the evaluated treatments, the insect (fall armyworm) causes high damage to the untreated plots, and after the first spray was done, the maximum infestation score (86.06%) was scored from unsprayed (Table 2). Accordingly, during all scoring dates, the unsprayed plots were the most exposed treatment to the insects and maximum crop deterioration occurred. At first spray, the damage score and infestation percentage on the untreated treatment was 5 and 86.05% respectively, while on the final date of spray, both infestation level and damage score were raised to 96.07% and 5 damage score respectively.

Table 1. Mean square values of FAW damage through three various spraying period (ANOVA).

Source of Variation	DF	After First Spray Infestation%	Damage score	After Second Spray Infestation%	Damage score	After Third Spray Infestation%	Damage score
Trt	3	4661.44***	12.17***	9201.48***	20.39***	14949.06***	28.034***
Replication	2	867.26**	6.08**	879.83**	5.81**	700.57*	2.87*
Location	1	1574.99**	3.0ns	1502.19**	6.75**	747.53*	1.54ns
Year	1	24.23ns	0.0ns	0.27ns	0.0ns	2.13ns	0.01ns
Trt*Location	3	107.18ns	1.72ns	122.98ns	0.92ns	187.85ns	0.36ns
Trt*Year	3	1.85ns	0.06ns	9.24ns	0.72ns	12.83ns	0.07ns
Error	34	117.91	0.84	91.93	0.66	135.32	0.6

NB: Where: DF- Degree freedom; **=; ns= non-significant.

The treatments treated with Con-Fidence 350SC (*Imidacloprid* 35% W/V) insecticide give the best response to the applied insects, and it causes major restriction on the insect from causing significant damage to the crop. The plots treated with Con-Fidence 350SC (*Imidacloprid* 35% W/V) infestation level after the first, second and third spray was 42.5%, 27.18%

and 16.44% respectively, while its damage scores were 2.75, 2.0 and 1.43 respectively. Rambo 24.7%EC is also the best insecticide for the management of fall armyworm following the Con-Fidence 350SC (*Imidacloprid* 35% W/V) insecticide at both Yabello and Abaya locations. The insect infestation level on plots treated with Rambo was 24.7%EC from the first spray

to the final spray was 46.27%, 36.39% and 28.13% respectively. Subsequently, the damage score was 3.0, 2.58 and 2.25, respectively, on plots treated with Rambo 24.7%EC insecticide. These results indicate the cumulative effectiveness of repeated applications, particularly in reducing late-stage infestations. [17] reported that the non-treated control plants had extensive leaf injury by FAW larvae compared to the synthetic insecticide and botanical-treated and no live larvae were recorded from plants sprayed with Radiant 120 SC, Karate 5 EC, and A. indica in the second- and third-round sprayings.

The damage caused by fall armyworm inhibition percentage of the insecticides was 82.89% compared to the unsprayed

treatment. The treatments applied with Con-Fidence 350SC (*Imidacloprid* 35% W/V) insecticide had the maximum inhibition percentage over the other treatments. This findings is consistent with [18] report that spinetoram and related insecticides effectively controlled FAW larvae, achieving the lowest larval populations. [19] Highlighted the efficacy of spinetoram against FAW in field applications. [20] confirmed that selected insecticides such as spinosad, emamectin benzoate, and chlorantraniliprole are effective and economically viable for FAW management. [21] Also evaluated synthetic insecticides, supporting their effectiveness in FAW control under field and laboratory conditions.

Table 2. Mean values of the treatments, location and year FAW damage on Maize.

Treatment	After First Spray Infestation%	Damage score	After Second Spray Infestation%	Damage score	After Third Spray Infestation%	Damage score
Con-Fidence 350SC	42.50 ^c	2.75 ^c	27.18 ^d	2.0 ^c	16.44 ^d	1.43 ^d
Rambo 24.7%EC	46.27 ^c	3.0b ^c	36.39 ^c	2.58 ^c	28.13 ^c	2.25 ^c
Unsprayed	86.05 ^a	5.0 ^a	89.91 ^a	5.0 ^a	96.07 ^a	5.0 ^a
Wantox40%EC	59.45 ^b	3.58 ^b	53.99 ^b	3.42 ^b	39.67 ^b	3.08 ^b
Mean	58.57	3.58	51.87	3.25	45.08	2.94
CV (%)	18.54	25.60	18.48	25.00	25.80	26.35
LSD (0.05)	9.01	0.76	7.95	0.68	9.65	0.65

LSD-Least significant difference, CV (%) - Coefficient of variation.

4.2. Crop Growth Parameters

4.2.1. Crop Flowering and Maturity Date

The analyzed data result revealed that there is no significant variation in flowering and maturity dates among the applied treatments. The overall mean values of the flowering dates were 75.75 dates. However, the maximum and minimum flowering date scored were 76 and 75.67 dates respectively. Similarly, the maximum and minimum dates of maturity were 96.25 and 95.83 dates respectively, with the overall mean value of maturity 96.06 dates (Table 4). Following this, the treatments had no effects on the flowering and maturity dates of the crop. [22] Reported that insecticide applications did not interfere with maize growth, including flowering and maturity stages. [23] observed no significant differences in arbuscular mycorrhizal fungi colonization or crop development stages

across treatments, indicating that insecticides did not affect flowering or maturity. [24], also found that foliar fungicide and insecticide applications did not significantly alter the timing of maize flowering or maturity. These studies support the current finding that insecticide applications, such as *imidacloprid*, can be applied without negatively impacting the timing of maize flowering and maturity.

4.2.2. Plant Height

As the analyzed data results revealed, the treatments were significantly varied in plant height. The scored plant height ranged from 170.08cm to 182.48cm with an overall mean of 177.9cm. The maximum and minimum plant height was scored from treatment with Con-Fidence 350SC(*Imidacloprid* 35% W/V) (182.48cm) and unsprayed (170.80cm) treatments.

Table 3. Square mean values of FAW effect on Maize yield components (ANOVA).

Source	DF	FD	MD	PHT (cm)	NCP	NDCP	HSW	GY (kg/ha)
Treatment	3	0.33	0.41	160.48*	0.21ns	3.26**	475.68**	22615888.50**
Replication	2	4.94	3.56	114.88ns	0.34ns	0.26ns	220.89**	1578150.10*
Location	1	0.08	6.02**	294.53*	0.84*	0.99**	160.24*	18354235.73**
Year	1	60.75**	93.52**	0.01ns	4.58**	0.34*	32.67ns	468.75ns
Treatment*Location	3	0.08	0.13	157.23*	0.05ns	0.31**	83.59*	2826557.47**
Treatment*Year	3	0.08	0.08	1.26ns	0.60*	0.0ns	0.16ns	434.03ns
Error Total	34	0.44	0.42	63.76	0.19	0.05	23.65	410968.8

NB: FD=Flowering date, MD=Maturity date, PHT=Plant height, NCP=Number of cob per plant, NDCP=Number of damaged cob per plant, CD=Cob diameter, HSW=Hundred seed weight, GY=Grain yield, CV=Coefficient of variation.

4.2.3. Number of Cobs Per Plant and Number of Damaged Cobs Per Plant

The cobs per plant and the damaged cobs per plant analyzed data revealed that there was a highly significant variation among the evaluated treatments. The treatments applied with Con-Fidence 350SC (*Imidacloprid* 35% W/V) insecticide had a maximum cob per plant and the unsprayed had minimum cobs per plant. The maximum number of damaged cobs per plant was scored from the unsprayed treatment, while the minimum damaged cob was scored from the treatment treated with Con-Fidence 350SC (*Imidacloprid* 35% W/V) insecticide (Table 4). [21] Reported that imidacloprid-treated maize plots had higher cob counts (1.67 cobs per plant) and reduced damage compared to untreated plots, demonstrating its effectiveness in protecting maize cobs.

4.2.4. Grain Yield

The results of analyzed grain yield data revealed that there was a highly significant ($P < 0.001$) variation among the evaluated treatments. The overall mean value of the grain yield obtained from the evaluated treatments was 2677.22kg/ha.

The maximum grain yield was obtained from a treatment applied with Con-Fidence 350SC (*Imidacloprid* 35%

W/V) insecticides and followed by the treatment applied with Rambo 24.7%EC. The minimum grain yield was obtained from the unsprayed (1126.0kg/ha) treatment (Table 4). Thus, the treatment with a low insect infestation and the lowest damage score (Con-Fidence 350SC (*Imidacloprid* 35% W/V)) achieved the maximum crop grain yield (4250.38kg/ha) and the unsprayed treatment or a treatment with a high insect infestation level and highest damage score had the minimum crop grain yield. Then, the insecticides had positive effects on the management of maize fall armyworm and results best yield achievement over the untreated plots. The finding is consistent with [21] report that imidacloprid-treated maize plots achieved yields of 4289 kg ha⁻¹ with reduced infestation, demonstrating the efficacy of this systemic insecticide. In southwestern Ethiopia, [25] observed that insecticides such as lambda-cyhalothrin effectively reduced infestation levels from 21.33% to 7.33%, enhancing yield performance. This, studies reinforce the current finding that maintaining low FAW infestation and damage levels is essential to achieving optimum maize productivity in dryland farming systems.

Table 4. Mean values of the treatments, location and year FAW damage on Maize yield components.

Treatments	FD	MD	PHT (cm)	NCP	NDCP	HSW	GY (kg/ha)	RYL (%)
Con-Fidence 350SC	76.0 ^a	96.17 ^a	182.48 ^a	1.73 ^a	0.38 ^d	33.96 ^a	4250.0 ^a	-
Rambo 24.7%EC	75.67 ^a	95.83 ^a	181.75 ^a	1.60 ^a	0.67 ^c	31.69 ^a	3288.3 ^b	22.64
Unsprayed	75.67 ^a	96.25 ^a	174.55 ^b	1.45 ^a	1.59 ^a	19.81 ^c	1126.0 ^d	73.51
Wantox40%EC	75.67 ^a	96.00 ^a	181.09 ^{ab}	1.46 ^a	1.04 ^b	26.37 ^b	2044.2 ^c	51.91
Mean	75.75	96.06	179.97	1.56	0.92	27.96	2677.12	
CV (%)	0.87	4.45	4.45	28.59	23.65	17.39	23.95	

Treatments	FD	MD	PHT (cm)	NCP	NDCP	HSW	GY (kg/ha)	RYL (%)
LSD (0.05)	0.55	0.54	6.62	0.37	0.18	4.04	531.87	

NB: FD=Flowering date, MD=Maturity date, PHT=Plant height, NCP=Number of cob per plant, NDCP=Number of damaged cob per plant, CD=Cob diameter, HSW=Hundred seed weight, GY=Grain yield, RYL=Relative yield loss, LSD=Least significance difference.

4.2.5. Relative Yield Loss

Then, the analyzed relative yield loss from the obtained maize grain yield data revealed that the highest loss (73.51%) occurred in the untreated plot than the other evaluated treatments and followed by the plot treated with Wantox40%EC (51.91%), while the minimum was observed from the plot treated with Con-Fidence 350SC (*Imidacloprid* 35% W/V) followed by Rambo (Table 4). The result revealed that use of Con-Fidence 350SC (*Imidacloprid* 35% W/V) insecticide is acceptable to avoid grain yield loss due to fall armyworm in maize.

4.2.6. Association of FAW Infestation and Grain Yield

The correlation analysis showed that very significant difference and strong positive relation between grain yield and yield components of the treatments. However, it was revealed that FAW infestation parameters showed a negative association and very significant variation with maize grain yield. The grain yield had a negative relation with maize damage formed after the final insecticide spray ($r=-0.965$, $p=0.035$). However, there was a positive ($r=0.999$, $p=0.017$) association between crop damage and FAW infestation percentage after final spray (Table 5).

Table 5. Grain yield correlations with yield components and FAW infestation on Maize.

Variables	GY (kg/ha)	NCP	NDCP	HSW	FAWi1s	Md1s	FAWi2s	Md2s	FAWi3s
NCP	0.970								
NDCP	-0.984	-0.913							
HSW	0.978	0.901	-0.997						
FAWi1s	-0.936	-0.823	0.982	-0.988					
Md1s	-0.932	-0.816	0.981	-0.985	0.999				
FAWi2s	-0.953	-0.850	0.991	-0.993	0.998	0.998			
Md2s	-0.967	-0.877	0.997	-0.996	0.993	0.993	0.998		
FAWi3s	-0.902	-0.772	0.964	-0.963	0.990	0.994	0.988	0.981	
Md3s	-0.965	-0.875	0.996	-0.992	0.989	0.991	0.996	0.999	0.983

NB: FAWi1s-Fall armyworm infestation after 1st spray, Md1s -Maize damage after 1st spray, FAWi2s - Fall armyworm infestation after 2nd spray, Md2s- Maize damage after 2nd spray, FAWi3s -Fall armyworm infestation after 3rd spray, Md3s- Maize damage after 3rd spray, PHT- Plant height, NCP-Number of cob per plant, NDCP-Number damaged cob per plant, HSW-Hundred seed weight, GY (kg/ha)-Grain yield in kilogram per hectare.

4.2.7. Economic Analysis

Based on the partial budget analysis result, all fall armyworm control treatments gave higher net benefit as compared to unsprayed/control. The net benefit of the evaluated treatments was estimated and described in Table 6. Con-Fidence 350SC (*Imidacloprid* 35% W/V) had the highest net

benefit of 189167.1ETB followed by the net benefit obtained from Rambo 24.7%Ec treatment (141103.5ETB). In contrast, the lowest net benefit (50670ETB) was obtained from unsprayed treatments. The profitability analysis revealed that the use of Con-Fidence 350SC (*Imidacloprid* 35% W/V) insecticide had a higher net benefit over the other treatments.

Table 6. The Economic analysis of different insecticides against FAW in maize production.

Treatments	Av. GY (kg/ha)	Ad. GY (kg/ha)	TGB (ETB/ha)	TVC (ETB/ha)	NB (ETB/ha)	MRR%
Unsprayed plot	1126	1013.4	50670	14000	50670	-
Wantox40%EC	2044.2	1839.78	91989	33050	72939	116.8976
Rambo 24.7%Ec	3288.3	2959.47	147973.5	39920	141103.5	992.2052
Con-Fidence 350SC	4250.38	3825.34	191267.1	42020	189167.1	2288.743

NB: Av. GY= Average Grain yield in kilogram per hectare; Ad. GY=Adjusted grain yield in kilogram per hectare; TVC (ETB/ha) = Total Variable Costs in Ethiopian birr; TGB= Total Gross Benefit (ETB/ha); NB= Net Benefit (ETB/ha); MRR= Marginal Rate of Return.

5. Conclusion and Recommendation

It is recommended that 350SC (*Imidacloprid* 35% W/V) be applied at a rate of 0.4 L/ha for effective fall armyworm management. Future efforts should focus on demonstrating this treatment on farmers' fields and promoting its adoption through extension services. Additionally, integrating this approach with other sustainable pest management practices is advisable to ensure long-term effectiveness and environmental safety.

Abbreviations

FAW	Fall Armyworm
LSD	Least Significant Difference
CV	Coefficient of Variation
SC	Suspension Concentrate
EC	Emulsifiable Concentrate
ANOVA	Analysis of Variance

Author Contributions

Rameto Nura: Formal Analysis, Writing – original draft, Writing – review & editing

Kemal Kitaba: Formal Analysis, Writing – original draft, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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