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Insecticide application schedules for fall armyworm *Spodoptera frugiperda* (Lepidoptera: Noctuidae) control and their partial budget impact on irrigated maize in the Raya Valley District, Tigray, Ethiopia

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Abstract

Focusing on the fall armyworm *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), a significant economic pest in Ethiopian maize capable of causing 50% field damage, this research aimed to determine the best application schedule for the insecticide Tutan 36% SC Plus in the Raya Valley District. The study documented significant differences in fall armyworm incidence and damage to maize leaves and cobs among the various treatment schedules. Treatments with more frequent applications (T10, T9, T8, T7) achieved superior pest control, evidenced by the lowest incidence and damage levels. In contrast, the highest pest incidence and damage occurred in the untreated control (T1) and treatments with fewer or poorly timed applications (T3, T2, T4, T5). This pattern is held for leaf injury, cob damage, and larval presence. Maize yield also varied significantly, ranging from 12.13 to 49.03 quintals per hectare. Maximum yields were associated with frequent applications (T10, T9, T8, T7), while minimum yields were recorded for the untreated control (T1) and plots with infrequent or suboptimal sprays (T2, T3, T4 and T5). Partial budgeting analysis indicated that the schedule of three bi-weekly applications (T7) was the most economically viable, yielding the highest Marginal Rate of Return (MRR) at 3916.865% and a mean grain yield of 44 qt/ha. The researchers conclude that this T7 schedule should be scaled up and demonstrated in the Rata Valley district and extended to other areas with similar agro-ecological conditions.

Introduction

Globally, maize (Corn) is ranked among the three most vital cereal crops, equivalent in importance to wheat and rice. It functions as a fundamental food source for numerous populations and provides significant economic benefits, particularly for resource-poor farmers (Abebe and Feyisa, 2017 and Marfo-Ahenkora, 2020). The crop exhibits substantial genetic variation and thrives in diverse environments, extending from the equator to approximately 50°N and 50°S latitude and reaching altitudes of up to 3800 meters (Ortega, 1987). Despite its critical role, maize cultivation is severely impacted by insects and mites that can attack the plant at any stage and in storage, leading to extensive damage. The most destructive group worldwide consists of moth species such as armyworms, cutworms, earworms, borers, and grain moths. Furthermore, beetles and sap-sucking insects like leafhoppers and aphids contribute to yield losses, often acting as vectors for diseases (Azerefegne *et al.*, 2002; Fotso *et al.,* 2019 and Ortega, 1987).

The fall armyworm *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), native to tropical and subtropical America, is a significant threat to maize. It's damaging larvae, which hatch from eggs, lay under leaves and feed on around 100 plant species but strongly prefer maize, rice, sorghum, and sugarcane (Abrahams *et al*., 2017). First detected in Africa in Nigeria in 2016 (Goergen *et al*., 2016), after several interceptions in Europe (Ibrahim and Jimma, 2018), it has now spread to 20 African countries, causing substantial maize damage and posing an economic threat. Current analysis indicates a high likelihood of permanent, large populations establishing in Africa (Paudel *et al*., 2022). Field studies also reveal that fall armyworm caterpillars cause more maize damage in West and Central Africa than other local *Spodoptera* species (Tendeng *et al*., 2019).

The fall armyworm (FAW) is a highly destructive pest of maize, causing significant yield losses from the seedling stage to the reproductive phase (Sileshi *et al*., 2022, and Demis and Jemal, 2024). An outbreak in Ethiopia, first reported in the Southern Nations, Nationalities, and Peoples' Region in 2017, subsequently spread to Oromia, Amhara, and Tigray. According to Sagar *et al.* (2020), this infestation caused devastating maize production losses, amounting to 30.54 million tons across the country, leading to substantial economic losses for farmers and the broader economy.

The use of systemic selective insecticides represents an effective approach to fall armyworm (FAW) management. According to Mukanga *et al.* (2024) and Karki *et al.* (2023) these agents are absorbed systemically by the plant, allowing them to target larvae that feed internally. Field investigations further substantiate the effectiveness of pyrethroid insecticides in mitigating FAW damage and infestation levels (Sileshi *et al*., 2022). Nevertheless, the fall armyworm constitutes a major threat to maize production, while prevailing control practices among farmers in the Raya Valley are largely inadequate. This inadequacy frequently arises from reliance on anecdotal evidence or historical experience for insecticide application, which contributes to suboptimal control outcomes and increased resistance development. Recognizing that the timing of application is critical and must align with the pest's developmental stages, this study is directed towards establishing the optimal application schedule for controlling FAW using the Tutan 36% SC Plus insecticide in the Raya Valley district.

Materials and methods

1. Description of study area:

The experimental site for 2024-2025 was in the Raya-azebo district, southern Tigray, Ethiopia, with controlled irrigation. Its coordinates are 12.41°N, 39.39°E, at an elevation of 1640 m. The district has two rainy seasons: a short one (Feb.-Apr.) and a main heavy one (Jul.-Sep.), averaging 724 mm yearly rainfall. Mean daily temperatures range from a maximum of 18.3°C/13.93°C (Highlands) to 23.44°C/19.64°C (Valley). The landscape is mostly "midland" (90%) with some "lowland" (10%). Farmers primarily use a mixed crop-livestock system, supplementing cattle feed with crop residues and chopped cacti during the dry season's feed shortages.

2. Experimental treatments and design:

The experiment utilized ten treatments to assess Tutan 36% SC Plus for fall armyworm (FAW) control, varying only in application timing (Table 1). Timing followed the product label, beginning after the first FAW detection and symptom appearance on maize. Each treatment was randomly allocated to a 10 m² plot (5m x 2m) with five maize rows, though only the central three rows were harvested. Plot spacing was 1 m, and block spacing was 2 m. Maize was planted manually in November 2024 at 30 kg/ha (10 cm spacing within rows, 40 cm between rows) into thrice-plowed plots. All plots received identical standard agronomic practices.

Table (1): Treatments used during the conduct of the experiment.

S. No.	Treatment	S. No.	Treatment
1	T1= No spray (control)	**6**	T6=Spraying insecticide at 2 & 4 WAE
2	T2=Spraying insecticide once at 2 WAE	**7**	T7= Spraying insecticide at 2, 4 & 6 WAE
3	T3= Spraying insecticide once at 4 WAE	**8**	T8= Spraying insecticide at 2, 4, 6 & 8 WAE
4	T4= Spraying insecticide once at 6 WAE	**9**	T9= Spraying insecticide at two-week interval WAE
5	T5=Spraying insecticide once at 8 WAE	**10**	T10= Spraying insecticide weekly (check) WAE

3. Agronomic data:

The following yield components were measured: plant height, cob number per plant, cob length, grain yield (kg/ha), and biomass (Ton/ha). Plant height was determined from ten random plants per plot. For cob number and cob length, ten random plants and their cobs from each plot were assessed. Grain yield (kg/ha) was calculated by threshing, winnowing, cleaning, and weighing the grain from each plot sample, then converting the weight to a per-hectare basis. Biomass (Ton/ha) was derived from material collected solely from the center row of each plot.

4. Insect data:

4.1. Incidence:

Fall armyworm (FAW) incidence on maize was calculated as the percentage of infested plants (Nono-Womdim *et al*., 1996). This percentage defined the incidence level: Low (1-20%) indicated minor plant impact, often requiring only monitoring; Moderate (21-50%) signaled significant crop infestation, suggesting the need for Integrated Pest Management (IPM); High (51-100%) denoted severe infestation affecting over half the plants, necessitating urgent and potentially aggressive control.

4.2. Severity:

The assessment of fall armyworm (FAW) severity (Damage) was conducted employing a standardized score scale, typically extending from 0 or 1, which signifies no damage, up to 9, representing the utmost level of damage (Davis and Williams 1992 and Ni *et al*. 2011). Further details regarding this scale are provided in Table (2). A specific classification scheme based on this scale categorizes severity as low for scores 0-4, medium for scores 5-7, and high for scores 8-9.

Table (2): Foliar damage on the upper leaves and whorl was assessed by scoring ten randomly selected plants, using the scale provided below.

Rating	Description of symptoms
1	Healthy plant, no visible damage.
2	Very slight damage, minor feeding marks.
3	Slight damage, small holes in leaves.
4	Moderate damage, noticeable leaf loss but still functional.
5	Moderate to severe damage, significant leaf area removed.
6	Severe damage, most of the leaf area affected.
7	Very severe damage, extensive leaf loss and plant health compromised.
8	Critical condition, nearly all foliage damaged; plant survival at risk.
9	Complete whorl destruction; plants likely dead.

5. Economic analysis:

Using CIMMYT Economics Program (1988) partial budgeting approach, this study assessed the economic feasibility of different insecticide treatments for fall armyworm in maize to find the most cost-effective schedule. Statistical tests first compared average yields across treatments; economic analysis followed only if yields differed significantly. Each treatment's details, costs, and benefits were organized via partial budgeting, considering both average yields and yields reduced by 10% (for potential farmer losses), gross field benefit, and variable costs. A 100% minimum acceptable marginal rate of return (MRR) was set as the decision threshold for farmer recommendations.

5.1 Gross return (GR) (ETB/ha):

It was obtained by multiplying the price from the farm that farmers get when they sell the adjusted yield.

5.2 Total varying Cost (TVC): It is the cost of insecticide and labor.

5.3 Net benefit (NB) (ETB/ha): Is the difference between gross return and total cost for each treatment. NB = GR – TVC.

5.4 The marginal rate of return (MRR %) quantifies the percentage gain in net return resulting from a specific change in cost. The calculation involves dividing the net return change by the cost change and multiplying by 100. MRR (%) = (Change in Net Return/Change in Cost) * 100.

6. Data analysis: Data analysis utilized R-Software version 3.6.2, employing ANOVA to assess yield components, and fall armyworm incidence and severity (Damage). Differences between treatment means were subsequently evaluated using the Least Significant Difference (LSD) test at the 5% significance level.

Results and discussion

1. Efficacy of the insecticide application schedule on maize leaves and cobs:

Current findings indicate highly significant ($p \leq 0.01$) differences among treatments concerning fall armyworm incidence and damage on maize leaves and cobs. Notably, weekly (T10) recorded 0% incidence, followed by bi-weekly (T9) at 10.33% and four times bi-weekly (T8) at 15.67%. Maximum incidence (100%) was observed in all treatments not previously mentioned, except for three times biweekly (T7). Leaf damage due to fall armyworm was minimal or absent in treatments T10 (weekly insecticide applications) and T9 (insecticide applied every two weeks), which showed low damage levels of 2.2%, 2.5%, 3.1%, and 3.5% at 25, 40, 55, and 70 days after emergence (DAE), respectively. Treatment

T8 also exhibited low damage, recorded as 2.4%, 2.53%, 3%, and 4% at the same assessment times. However, significantly higher damage occurred in the untreated control (No spray): 7.8%, 23.67%, 27.83%, 56.9% at 25, 40, 55, 70 DAE, followed by T2 (6.9%, 16.6%, 22.43%, 54.73%) and T3 (7.8%, 16.6%, 26%, 50.4%) (Table 3).

Treatments T10, T9, and T8 were notable for their low COB incidence rates. T10 exhibited the lowest or negligible incidence, followed by 5.1% in T9 and 6.9% in T8. All other treatments recorded incidence rates exceeding 50%. A similar trend was observed for cob damage, where T10 showed the least damage at 0%, followed by T9 (1.37%), T8 (3.07%), and T7 (8.3%). The untreated control plot, however, showed the highest cob damage at 12.5%, which was significantly greater than the damage levels in T3 (11.1%), T4 (10.73%), and T2 (10.53%) (Table 3). Damage to the kernels within the ear leads to direct reductions in grain weight and quantity. Larvae can consume significant portions of the cob.

Table (3): Measured percentage of plants infested with fall armyworm (FAW), based on visible larval symptoms on leaves and the whorl, across four assessment days.

Treatments	Leaf incidence and damage					Cob I and D	
	I (%)	25 DAE	40 DAE	55 DAE	70 DAE	I (%)	D (%)
T1	100a	7.8ab	23.67a	27.83a	56.9a	100a	12.27a
T10	0d	0b	0d	0d	0d	0c	0e
T2	100a	6.9ab	16.6b	22.43ab	54.73a	100a	10.53ab
T3	100a	7.8ab	16.6b	26a	50.4a	100a	11.1ab
T4	100a	8.4ab	12.97bc	17.07bc	49.57a	100a	10.73ab
T5	100a	10a	17.87b	27.3a	50a	100a	10.2b
T6	100a	4.9ab	10.47c	19.03b	37b	55.67b	9.4bc
T7	30b	5.3ab	3.4d	11.33c	19.67c	55.67b	8.3c
T8	15.67c	2.4ab	2.53d	3d	4d	6.9c	3.07d
T9	10.33d	2.2ab	2.5d	3.1d	3.5d	5.1c	1.37de
Mean	64	5.76	11.15	15.86	32.8	61.1	7.7
CV (%)	2.7	70.4	27	21.3	32.86	12.4	13.5
Lsd (5%)	2.914	6.95	5.156	5.8	32.86	12.97	1.78

Note; D: Damage, I: Incidence, DAE: Days after emergence; WAE: Weeks after emergence; T1: Control; T10: Weekly spray; T2: Spraying once at 2 WAE; T3: Spraying once at 4 WAE; T4: Spraying once at 6 WAE T5: Spraying once at 8 WAE; T6: Spraying once at 2&4 WAE; T7: Spraying once at 2, 4 & 6 WAE; T8: Spraying once at 2, 4 & 6 WAE; T9: bi-weekly (T9)

2. Mean injury levels of leaves and cobs due to fall armyworm:

Analysis of Variance (ANOVA) results indicated a highly significant difference ($p < 0.01$) among treatments concerning the fall armyworm (FAW) injury score on maize leaves and cobs. This demonstrates that different schedules for applying insecticides affect FAW control and subsequent infestation levels. The lowest FAW injury scores on leaves were observed in treatment T10 (0.33, 0.67, 0.51, 0.53), followed by T9 (0.67, 0.53, 0.56, 0.83) and T8 (0.67, 0.67, 0.77, 1.73) at the 25, 40, 55, and 70-day assessment intervals, respectively. Conversely, the highest injury scores were recorded in the untreated control plot (Unsprayed: 1.5, 4.27, 5.73, 7.47), followed by treatments T2 (1, 3.33, 4.57, 7.4), T3 (1.5, 3.27, 5.27, 7.17), and T4 (1.67, 2.5, 3.3, 7.07) at the same assessment days. Comparable to leaf injury, cob infestation levels showed distinct treatment effects. The lowest or non-existent FAW infestation on cobs occurred in

T0 (0), followed by T9 (0.33) and T8 (0.67). In contrast, the highest infestation scores on cobs were measured from T1 (2.4), T3 (2.2), and T4 (2.2) (Table 4).

Table (4): Average leaf and cob injury score (Scale 1-9) assessed at four different times.

Treatments	Leaf injury score				Cob injury score
	25 DAE	40DAE	55 DAE	70DAE	
T1	1.5a	4.27a	5.73a	7.47a	2.4a
T10	0.33a	0.67d	0.51f	0.53e	0d
T2	1a	3.33b	4.57ab	7.4a	2.17ab
T3	1.5a	3.27b	5.2ab	7.17a	2.2ab
T4	1.67a	2.5bc	3.3de	7.1a	2.2ab
T5	1.33a	3.4ab	5.33ab	7.07a	2.07ab
T6	1a	1.8c	3.77cd	5.3b	1.97ab
T7	1a	0.67d	2.5e	4.03c	1.73b
T8	0.67a	0.67d	0.77f	1.73d	0.67c
T9	0.67a	0.53d	0.567f	0.83de	0.33cd
Mean	1.1	2.12	3.24	4.88	1.573
CV (%)	26.9	25.1	20.5	11.8	24.5
LSD (5%)	1.4	0.91	1.14	0.99	0.6608

Note; DAE: Days after emergence; T1: Control; T10: Weekly spray; T2: Spraying once at 2 WAE; T3: Spraying once at 4 WAE; T4: Spraying once at 6 WAE T5: Spraying once at 8 WAE; T6: Spraying once at 2&4 WAE; T7: Spraying once at 2, 4 & 6 WAE; T8: Spraying once at 2, 4 & 6 WAE; T9: bi-weekly (T9).

3. Assessing the presence and incidence of fall army worm larvae on maize leaves:

The ANOVA analysis revealed a significant effect of treatment on larval incidence. Treatments T10, T9, and T8 were highly effective, showing the lowest or negligible larval counts (T10: lowest/absent; T9: 0.09, 0.24, 0.21, 0.27; T8: 0.07, 0.2, 0.25, 0.37). In stark contrast, the untreated control had the highest larval numbers (0.6, 4.47, 5.67, 5.07), significantly exceeding those in T2 (0.2, 1.07, 2.47, 5.46) and T3 (0.5, 0.17, 3.17, 4.33) (Table 5). Figure (1) clearly illustrates the presence or absence of larvae and the resulting impact of the fall armyworm on maize leaves, cobs, and grain, making these observations straightforward.

4. Yield and yield component:

Significant treatment effects ($p<0.01$) were observed on maize yield and its components. Specifically, the number of cobs per plant differed significantly among treatments. Treatments weekly (T10), biweekly (T9), four times biweekly (T8), or three times biweekly (T7) yielded the best results with approximately 1.6 cobs per plant, while treatments T1 (control), T2, and T4 produced fewer cobs. Cob length showed a significant variation as well, with T10 achieving the longest cobs (18.07 cm), followed by T7 (17.37 cm) and T9 (16.53 cm). In contrast, the untreated control T1 had significantly shorter cobs (8.73 cm). Plant height exhibited a similar trend, with the tallest plants found in T10 (238.3 cm) and T7 (232.5 cm), and the shortest in the untreated T1 (146.3 cm) and T5 (183.8 cm). Strew levels were highest in the effective treatments (T10, T7, T8, T9) and considerably lower in T1, T4, T5, and T3, suggesting differential fall armyworm impact.

Grain yield ranged from a low of 12.13 qt/ha in the control (T1) to a high of 49.03 qt/ha in T10. The top-yielding treatments were T10 followed by T9, T8, and T7, with respective yields of 49.03, 47.83, 46.43, and

44 qt/ha. Conversely, lower yields were recorded for the control (T1), T5, T3, and T4 (12.13, 21.33, 22.77, and 23.33 qt/ha, respectively). This indicates that the insecticide application schedule was effective in controlling fall armyworm and boosting maize yield compared to the unsprayed control. A yield advantage was observed for treatments T10, T9, T8, and T7, with respective yields of 36.9, 35.7, 34.3, and 31.87 qt/ha, compared to the unsprayed control (Table 6).

Table (5): Effectiveness of insecticides against fall armyworm larvae.

Treatments	Number of larvae per plant			
	25 DAE	40 DAE	55 DAE	70 DAE
T1	0.6a	4.47a	4.67a	5.07
T10	0c	0.1b	0.1b	0.1b
T2	0.2bc	1.07b	2.47b	5.46a
T3	0.5ab	0.17b	3.17b	4.33ab
T4	0.6a	1.6b	3.67b	4.13ab
T5	0.47ab	4.6a	5.33a	0.67cd
T6	0.27bc	0.03b	1.27c	2.67bc
T7	0.03c	0b	0.13d	1.4cd
T8	0.07c	0.2b	0.25d	0.37d
T9	0.09bc	0.24b	0.21d	0.27d
Mean	0.297	1.39	1.87	2.52
CV (%)	62.3	54.3	32.8	47.7
LSD (5%)	0.317	1.297	1.052	2.062

Note; DAE: Days after emergence; T1: Control; T10: Weekly spray; T2: Spraying once at 2 WAE; T3: Spraying once at 4 WAE; T4: Spraying once at 6 WAE T5: Spraying once at 8 WAE; T6: Spraying once at 2&4 WAE; T7: Spraying once at 2, 4 & 6 WAE; T8: Spraying once at 2, 4 & 6 WAE; T9: bi-weekly (T9.)

Figure (1): The effect of fall armyworm (FAW) on maize leaves, cobs, and grain.

Table (6): Effect fall army worm on yield and yield components.

Treatments	NCPP	Cob Length (cm)	PH (cm)	Yield (qt/ha)	Biomass (ton/ha)	Yield advantage (qt/ha)
T1	1c	8.73c	146.3d	12.13d	10.93e	-
T10	1.733a	18.07a	238.3a	49.03a	19.24a	36.9
T2	1.07bc	11.87bc	197.2bc	25.33bc	11.24de	13.2
T3	1.2bc	11.73bc	196.9bc	22.77c	13.62cd	10.64
T4	1.13bc	12.67abc	187.9c	23.33c	12.1de	11.2
T5	1.267b	16.01ab	183.8c	21.33c	13.14de	9.2
T6	1.267b	15.6ab	186.4c	31.5b	15.71bc	3.58
T7	1.6a	17.37ab	232.5a	44a	18ab	31.87
T8	1.533a	15.93ab	230.4a	46.43a	16.48b	34.3
T9	1.6a	16.53ab	226.1ab	47.83a	17.98ab	35.7
Mean	1.34	14.51	201.6	32.37	14.84	
CV (%)	11.2	24.1	7.8	11.6	9.9	
LSD (5%)	0.2583	6.008	26.93	6.5	2.5	

Note; cm: Cent meter; NCPP: Number of cobs per plant; PH: Plant height; qt/ha: Quintal per hectare, Ton/ha: Ton per hectare, SW: Seed weight; T1: Control; T10: Weekly spray; T2: Spraying once at 2 WAE; T3: Spraying once at 4 WAE; T4: Spraying once at 6 WAE T5: Spraying once at 8 WAE; T6: Spraying once at 2&4 WAE; T7: Spraying once at 2, 4 & 6 WAE; T8: Spraying once at 2, 4 & 6 WAE; T9: bi-weekly (T9).

5. Partial budget analysis:

The research employed partial budget analysis to assess total variable costs and net benefits associated with different treatments. Through dominance analysis, cost-benefit evaluations, and marginal rates of return (MRR), the study identified superior treatments. The percentage MRR (% MRR), calculated for each treatment pair, quantified the return on investment for insecticide application. A key finding was the positive impact of a three-time spray frequency on maize profitability when dealing with fall armyworm (FAW). Treatment T7, involving three sprays at two-week intervals, achieved the highest MRR (3916.865%) and the maximum mean grain yield (44 qt ha^{-1}), demonstrating it as the most profitable method under the study's conditions (Table 7). Therefore, the application of insecticide three times at two-week intervals for controlling FAW in maize production was deemed the most economically advantageous strategy in the Raya Valley district. Partial budget analysis provides a framework for comparing costs and benefits of alternatives in farm business decisions. It is especially valuable for evaluating the profitability of minor, targeted changes within an intervention.

Table (7): Marginal rate of return of insecticide application schedule on maize yield.

Treatments	Adj. Grain yield (qt/ha)	Straw yield (Ton/ha)	TVC (ETB)	Net Benefit	MC	MB	MRR	MRR (%)
T1	10.917	10.93	0	96106				
T2	22.797	11.24	3250	165004	3250	68898	21.19938	2119.938
T3	20.493	13.62	3250	157344	0	-7660		
T4	20.997	12.1	3250	156412	0	-932		
T5	19.197	13.14	3250	148524	0	-7888		
T6	28.35	15.71	6500	208188	3250	59664	18.35815	1835.815
T7	39.6	18	8350	280650	1850	72462	39.16865	3916.865
T8	41.787	16.48	9000	287066	650	6416	9.870769	987.0769
T9	43.047	17.98	12250	294376	3250	7310	2.249231	224.9231
T10	44.127	19.24	20500	294134	8250	-242	-0.02933	-2.93333

Note; TVC: Total variable cost; MC: Marginal cost; MB: Marginal benefit; MRR: Marginal rate of return; T1: Control; T10: Weekly spray; T2: Spraying once at 2 WAE; T3: Spraying once at 4 WAE; T4: Spraying once at 6 WAE T5: Spraying once at 8 WAE; T6: Spraying once at 2&4 WAE; T7: Spraying once at 2, 4 & 6 WAE; T8: Spraying once at 2, 4 & 6 WAE; T9: bi-weekly (T9).

Insect pests significantly threaten agricultural output by reducing crop yields, quality, and the aesthetic appeal of non-edible plants. The nutritional profile of a plant is a key factor influencing which plants are chosen by feeding insects (Abrahams *et al*., 2017). The fall armyworm is a critical pest of maize, and insecticides are considered a primary tool for its control (Capinera, 2000). Insecticide applications were significantly more effective ($p<0.01$) against fall armyworm larvae, resulting in less leaf damage and higher maize grain yields compared to the untreated plants. The current finding indicates that applying insecticides weekly (T10), bi-weekly (T9), four times biweekly (T8), or three times biweekly (T7) provided the best control against FAW, substantially lowering leaf damage (upto-56.9%) and larval numbers compared to the control. However, a concurrent four-day assessment of leaf/whorl damage across all treatments showed highly variable results, indicating inconsistent performance and shifting pest pressure, likely due to complex pest-plant-intervention interactions. This underscores the importance of targeting vulnerable larvae, applying insecticides precisely and at correct dosages, as emphasized by previous studies by Akeme *et al.* (2021) and Assefa and Ayalew (2019), for effective, safe, and resistance-managed control. Damage levels varied significantly across treatments, with the most frequent applications (T7-T10) causing the least harm, confirming that infrequent or no applications (like the control or T5, T3, T4, and T2, respectively) are ineffective for FAW management, aligning with earlier findings (Kamunhukamwe *et al*., 2022).

The experiment showed that applying insecticide treatments led to the highest mean grain yields. These were achieved with treatments T10 (weekly), T9 (biweekly), T8 (four biweekly), and T7 (three biweekly applications). In contrast, the lowest yields were observed in the untreated control group, followed by treatment T5, which involved a single application eight weeks after emergence. Larval feeding is the main cause of severe FAW damage to maize (Abrahams *et al*., 2017). This polyphagous pest, as described by Ishola *et al.* (2022), feeds sequentially: starting on leaves, then moving to vital parts such as the whorl, stalk, tassels, and ears. Leaf damage reduces yield indirectly by impairing photosynthesis, whereas direct damage to the cob destroys grain, causing the most significant yield impact, as presented in Figure (1). These devastating production losses from FAW infestation are consistent with the findings of Sagar *et al.* (2020).

The experiment demonstrated that insecticide treatments, particularly the frequent ones (T7-T10), resulted in the highest grain yields, as presented in Table 4. These treatments were significantly more effective ($p<0.01$) than no treatment, leading to less leaf damage and higher yields. Stover biomass also varied but fell within typical ranges. Young larvae disrupt photosynthesis by feeding on leaves, while older caterpillars damage reproductive structures (tassels, silks, and ears), reducing grain quality, increasing susceptibility to fungal infections and aflatoxins, and lowering overall yield (figure 1). The plant's resource diversion for defense against infestation further contributes to yield. As presented in Table 5, economic analysis via partial budgeting (CIMMYT Economics Program (1988)) found treatment T7 (three times biweekly) to be the most effective, yielding the highest MRR (3916.865%) and maximum mean grain yield (44 ha^{-1}). This demonstrates that the treatment is highly profitable and leads to significant yield improvements, findings that are consistent with Bale-Robe (2024) regarding the economic analysis of food barley. This study aligns with Tekle (2015), who found that the most attractive combination for small-scale farmers offering low production costs and higher benefits was 82 kg N/ha with a 10 cm intra-row spacing. For resource-rich producers, however, who recommended the higher-cost but highest net benefit combination of 82 kg N/ha applied at 5 cm intra-row spacing.

S. frugiperda, commonly known as the fall armyworm, is a highly polyphagous agricultural pest, primarily targeting maize. The research demonstrated that the frequency of insecticide applications directly influences fall armyworm incidence, infestation severity, and the extent of larval damage. Treatments involving more frequent applications—T10 (weekly), T9 (bi-weekly), T8 (four biweekly), and T7 (three biweekly)- consistently exhibited the lowest pest incidence and damage. This positive effect translated directly to yield, with these treatments achieving maximum yields, while the untreated control and treatments T5, T3, T4, and T2 resulted in minimum yields. Partial budget analysis confirmed the economic superiority of T7 (three biweekly applications), which delivered the highest MRR (3916.865%) and a mean grain yield of 44 qt/ha. Therefore, T7 is the most effective recommendation for maize production in the Raya Valley district. Further scaling up and demonstration of this technology within the Raya Valley, and its extension to other regions with comparable agro-ecological conditions, is recommended.

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