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The Control of Fall Armyworm (*Spodopterafrugiperda*, Lepidoptera, Noctuidae) and its Damage on Maize Using Neem Oil in South Ethiopia

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Abstract

Field trials were conducted at two locations in the South Omo zone to evaluate the effect of neem oil concentration and its application frequencies on reducing fall armyworm damage on maize. The experiment was laid out in a randomized complete block design comprising five concentrations of neem oil (NO) and two frequencies and replicated three times. Percentage of infested plants, leaf damage, and maize yield were collected and analyzed. Concentrations and intervals have shown a significant effect on variables such as the percentage of infested plants, leaf damage, the number of cobs per plant, cob length, and grain yield. The lowest rate of plant infestation and leaf damage was recorded from the weekly application of NO 3% next to the application of standard insecticide. Similarly, the highest grain yield was obtained from the weekly application of 3% NO, comparable with the standard insecticide-diazinon. Therefore, due to damage reduction and the highest yield obtained from weekly application of 3% NO, it was recommended as an alternative option to synthetic chemicals. Integration of recommended neem oil concentration with other options is important for fall armyworm management in the maize production system of the study area.

Keywords: *Spodopterafrugiperda, Maize, Biopesticide, Evaluation, Safer option, Infestation*

Introduction

Maize (*Zea mays* L), is the most important crop produced in Ethiopia for Economic, livelihood, industrial, resilience to climate, and food security purposes. It is one of the country's staple crops, grown extensively across diverse agro-ecological zones. Ethiopia ranks as the fourth-largest maize producer in Africa, following South Africa, Nigeria, and Egypt. The crop is cultivated predominantly by smallholder farmers, accounting for over 90% of production, with Oromia, Amhara, and the Southern Nations, Nationalities, and Peoples' Region (SNNPR) being the primary maize-growing regions [1]. Maize is cultivated on approximately 2.5 million hectares of land in Ethiopia, producing an average yield of around 4 tons per hectare, significantly higher than many other African countries. This yield improvement is attributed to the adoption of improved technologies such as high-yielding maize varieties, better agronomic practices, pest management, and extension services provided by agricultural development programs [2]. However, production levels are highly variable due to factors such as rainfall dependency, pests (e.g., fall armyworm), and limited access to inputs like fertilizers and improved seeds [3] [4]

The fall armyworm (*Spodopterafrugiperda*, Lepidoptera, Noctuidae), which is native to the Americas invaded many parts of the African continent [5] and has become a major pest of many plant species, with a strong preference for maize [6] [7]. The fall armyworm (*Spodoptera frugiperda*), an invasive pest, poses a severe threat to Ethiopia's agricultural sector, particularly maize production leading to significant economic losses. FAW infestations have resulted in a national loss of approximately 0.67 million tonnes of maize, valued at $200 million, between 2017 and 2019. This pest threatens food security for millions, particularly in rural areas dependent on maize cultivation. These losses equated to the maize consumption needs of 4 million food-insecure households during this period. The fall armyworm's impact varies by agroecology, with high infestation rates reported in mid-altitude maize-growing regions [8] [9] [10].

FAW can have many generations per year depending on environmental conditions. Adult females can live 10–21 days and lay up to 1,000 egg masses in their lifetime. Larva of fall armyworm can be identified based on inverted "Y" marking on the head area, four large dorsal spots on the second last segment in a near square arrangement, pale dorsal line, and lighter ventral and dorsal area [11] [12].

Fall armyworm feeds on whole maize plant parts and causes yield loss in severe infestation [5] [13]. In Ethiopia, FAW can cause yield losses ranging from 20% to 80%, depending on the level of infestation and management practices employed [9] [10]. [14] also reported that FAW infestation occurred on a quarter of the 2.9 million ha of land, resulting in a loss of more than 134 million tons. The pest added burden on farmers by increasing the cost of insecticide use reducing income [15] [16] and resulting in secondary fungal infection and mycotoxin levels [17] [18].

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Management of the fall army appears challenging due to the availability of a diverse range of host plants throughout the year; favorable climatic conditions for its growth and development, its short life cycle, rapid multiplication, and ability to spread across large geographical areas [19] [20] [14].

Fall armyworm management strategies such as insecticides, host-plant resistance, cultural practices, crop rotation, and integrated pest management (IPM) approach are used to control FAW [21] [15] [22]. Researchers in Ethiopia emphasize integrated pest management (IPM) strategies. For instance, intercropping and climate-adapted "Push-Pull" techniques [23] have shown promise, reducing FAW infestations by over 80%. Biological control methods, including natural predators, parasitoids, and microbial agents, are gaining attention as sustainable alternatives to chemical pesticides [10] [24]. Most farmers use synthetic insecticides frequently, as the main response and effective means to control fall army infestation [7] [25] [26]. Frequent application of chemicals is unsustainable in that it negatively impacts the environment, causes a decline in biodiversity and beneficial arthropods, leads to insecticide resistance, and endangers the health of growers and consumers [27] [19].

Botanical pesticides like neem oil (*Azadirachta indica*) have gained attention as an eco-friendly and sustainable pest management strategy. Several studies proved the potential of plant extract as an alternative insect pest control agent [28] [29]. Research has been conducted to understand the effects of varying concentrations and application intervals of neem oil on the control of fall armyworms in maize. Neem-based bio-pesticides derived from *Azadirachtaindica* (from its leaves, seeds, seed oil, seed cake, and bark) are reported as well-known means for controlling fall armyworms. Neem seed and leaf extracts have great potential as a natural insecticide for the management of fall armyworms [30]. Neem affects insects by repelling and inhibiting feeding, inhibiting metamorphosis, impairing fitness and reproductive ability, and deterring egg-laying". Oil extracted from neem has been reported to be effective in reducing fall armyworm damage on maize [31] [32] [33] [34] [35] [36]. In Ethiopia Research demonstrates that neem oil (*Azadirachta indica*) can effectively control fall armyworm when applied in appropriate concentrations and intervals. Higher concentrations, such as 1–3%, and shorter application intervals of 7–10 days are most effective in reducing larval populations [37]. Neem oil disrupts feeding, growth, and reproduction, aligning with integrated pest management principles. Despite challenges like labor intensity and environmental variability, neem oil enhances maize yield and reduces pest impact [38].

Surveys indicate that 97% of Ethiopian farmers are aware of FAW, with many adopting traditional control methods like handpicking caterpillars and applying wood ash. Maize growers in the South Omo zone mainly use frequently high doses of synthetic chemicals including Diazinon 60% EC for controlling severe fall army worm infestation. This practice speeds up resistance development against insecticides and increases the cost of production and health risks (Personal communication). In addition, existing methods alone are insufficient to address the widespread infestation, necessitating broader, scientifically backed interventions [9]. The use of neem products, such as neem oil derived from neem seeds has been expanded as a pesticide plant against FAW elsewhere under laboratory trial and should be evaluated under field conditions. Limited work exists on the effectiveness of neem oil in field-based evaluation in the study areas. Therefore, testing the efficacy of botanical neem oil extracts under field conditions is important to establish their effectiveness. As a result, the current study focused on controlling fall armyworm damage on maize crops using neem oil with the following objectives.

- To evaluate the effectiveness of neem oil extracts on fall armyworm infestation, damage, and yield of maize crop

Material and Methods

The experiment was conducted in the two locations of South Omo zone, Ethiopia (at the research field of Jinka Agricultural Research Center and Dassenech woreda, during the 2019/2020 main cropping season; Jinka geographical coordinates are 5° 17' 0" N, 36° 46' 0" E and 1490 meters above sea level. The area has an annual Minimum temperature of 15^{0}c and a maximum of 36.6^{0}c. Dasenech woreda geographical coordinates are 54°37′ 25′′ & 4°48′ 16′′ North & 35°56′ 12′′ and 36°20′ 34′′East 353 meters above sea level. The Dasenech area has a 30^{0}C minimum and 40^{0}C maximum temperature as information averaged over the long term by the metrological agency. Both trial site has a bi-modal rain pattern with the main rainy season, from March to May, and a mild, minor rainy season, from September to December. Maize is cultivated mostly in the study areas. Pests are one of the factors limiting maize production in the study areas.

Experimental Design, Planting, and Treatments

The experiment consisted of three concentrations of neem oil (1% neem oil, 2%neem oil, 3%Neem oil), Detergent, standard insecticide diazinon, and untreated (spray water only). Treatments were applied in two intervals (weekly and fortnightly) application and untreated control (sprayed water only)form 11 total treatment combination(T1= Detergent Weekly, T2= NO 1%Weekly, T3= NO 2%Weekly, T4= NO 3%Weekly, T5= DiazinonWeekly, T6= Detergent Fortnightly, T7= NO 1%Fortnightly, T8= NO 2%Fortnightly, T9= NO 3%Fortnightly, T10= Diazinon Fortnightly, T11= Control. The treatments are arranged in a Randomized complete block design with three replications. The trial sites were tractor-plowed and harrowed to good soil tilth. After the land was prepared, the Melkassa-4 maize variety was planted on the plot with a row cropping method of five rows on 16/8/2020. Plot size was 5m x 5m at both sites. The space between rows and plants was 75cm by 25cm, respectively. The blocks were separated by a 5m gap while the experimental plots were separated by a 3m gap. 100 kg/ha NPSB was applied at planting time and 100kg/ha urea was applied in split application. Half of the urea was at planting and half was at 45 days after crop emergence. Weed control was done manually at three to six weeks after crop emergence.

Plant Extract Preparation and Treatment Application Procedures

Neem oil extracted from neem seed is widely used as a bio-insecticide due to the high concentration of oil it contains. Among several methods to obtain oil from neem seed, mechanical method was used. In the current study, seeds of *Azadirachta indica* were collected from the field; dust was removed, cleaned by washing with tap water, and sun-dried for 4 days. The pulps/flesh tissues were separated from the seed, the cleaned seed was crushed into powder using a mechanical method using a mortar and piston to obtain the powder, and then the powder was sieved using a sieve.

Cleaned extracts were placed in hermetically closed boxes and stored in a dark place in the laboratory. The neem oil concentrations were prepared by mixing 10, 20, and 30 ml of neem oil and 1, 2, and 3 ml of liquid soap in one liter of water for each concentration, respectively. 3ml of detergent mixed in one liter of water was also sprayed. Diazinon insecticide was applied at the recommended rate of 1.5l/ha. Control plots were sprayed with water only. A knapsack sprayer was used to apply the treatments. After spraying, the sprayer was washed with liquid soap and water once and then rinsed with water twice. The spraying was done in the late afternoon between 4:30 and 6:00 pm hours to escape the effect of sunlight on the efficacy of neem oil.

Picture 1. Infected and healthy maize

Data Collection

Fall armyworm infestation

Assessment of initial fall armyworm damage was started 20 days after planting in both locations by examining 10 consecutive maize plants along two diagonals on each plot. Data on the percentage of infested plants was taken 14, 28, and 42 days after the first application. The sample was taken early in the morning and late in the afternoon when fall armyworm larvae were active [39]. The level of infestation on maize plants was calculated using the following formula.

$$\text{Percentage of infested plants} = \frac{Number\ of\ plants\ attacked\ by\ fall\ armyworm}{total\ number\ of\ plants\ scouted} x100$$

Foliar/leaf damage rating

The visual rating of maize leaf damage can be done based on the number and size of lesions observed on the leaves. To rate the impact of fall armyworm on maize leaf and simultaneously to determine the efficacy of used treatments, the severity of leaf damage was visually rated on 10 randomly selected plants from different locations in the experimental plots 42 days after the first treatment application based on simplified day independent 0-9 rating scale as described by [40]: 0= No visible damage;4=Small elongated and a few midsized elongated lesion on whorl and,/or furl leaves; 9= Whorl and furl leaves destroyed. The median was calculated first and subjected to ANOVA. The reason for using Davie's rating scale was due to it is the most frequently used leaf damage scoring scale under natural infestation of fall armyworm at any maize vegetative growth stage and independent of larval instars.

Table 1. Leaf damage rating of FAW based on [40]

Score	Damage Symptoms
1	No visible leaf-feeding damage
2	Few pinholes on 1-2 older leaves
3	Several shot-hole injuries on a few leaves (<5 leaves) small circular hole damage to leaves
4	Several shot-hole injuries on several leaves (6–8 leaves) or small lesions/pinholes, small circular lesions, and a few small elongated (rectangular-shaped) lesions of up to 1.3 cm in length present on whorl and furl leaves
5	Elongated lesions (>2.5 cm long) on 8-10 leaves, plus a few small- to mid-sized uniform to irregular-shaped holes (basement membrane consumed) eaten from the whorl and,/or furl leaves
6	Several large elongated lesions are present on several whorl and furl leaves and,/or several large uniform to irregular-shaped holes eaten from furl and whorl leaves.
7	Many elongated lesions of all sizes are present on several whorl and furl leaves plus several large uniform to irregular-shaped holes eaten from the whorl and furl leaves.
8	Many elongated lesions of all sizes are present on most whorl and furl leaves, and many medium to large-sized uniform to irregular-shaped holes are eaten from the whorl and furl leaves.
9	Whorl and furl leaves are almost destroyed and plants die from extensive foliar damage.

Maize Yield parameters

Three inner rows of maize were harvested excluding the outer border rows to avoid border effect. Data on the number of cobs per plant was recorded on average by visually counting the number of cobs per sampled plant, cob lengths were measured using calibrated tape(meter). Maize cobs were dried and manually threshed by hand, winnowed and grains were dried by sun drying to 12–13% moisture content. Grain yield was assessed per plot by using scale balance. After measurement of the weight of grains per plot, it was converted to yield on a kg per ha basis.

Data Analysis

Data sets were subjected to statistical analysis using the SAS software. The dependent variables such as the percentage of infested plants, maize leaf damaging rate, and maize yield component parameters were subjected to one-way analysis of variance (ANOVA, P<0.05) to test the main effect of treatments and two-way analysis of variance (ANOVA, P<0.05) to test the interaction between factors treatments. Significant means were separated by Tukey HSD (p<0.05) level of significance.

Results and Discussion

Table1.Effect of neem oil concentration, frequency, and their interaction on percent plant infested

Concentration	Percent Plants infested					
	Jinka			Dassenach		
	14 DAA	28 DAA	42 DAA	14 DAA	28 DAA	42 DAA
DO	61.67a	65.00a	65.00a	78.33a	70.00a	70.00a
NO 1%	46.67b	41.67b	36.67b	55.00b	56.67b	48.33b
NO 2%	28.33c	26.67c	23.33c	40.00c	38.33c	31.67c
NO 3%	25.00c	21.67c	20.00c	31.67cd	31.67cd	25.00c
Diazinon	10.00d	5.00d	8.33d	23.33d	26.67d	8.33d
Control	62.02a	66.23a	65.05a	80.00a	73.33a	73.33a
Significance	*	*	*	*	*	*
Frequency						
Weekly	31.33a	28.67b	28.00b	48.33a	48.89a	40.56b
Fortnightly	37.33a	35.33a	33.33a	54.44b	50.00a	45.00a
Significance	Ns	*	*	*	Ns	*
Concentration x Frequency						
T1	60.00ab	60.00a	63.33a	76.67a	70.00ab	70.00a
T2	43.33bcd	36.67bc	33.33bc	53.33b	53.33bc	43.33bc
T3	23.33efg	23.33d	20.00de	36.67cd	40.00cd	30.00de
T4	23.33efg	20.00d	16.67def	26.67de	33.33d	20.00ef
T5	6.67g	3.33e	6.67f	16.67e	23.33d	6.67g
T6	63.33a	70.00a	66.67a	80.00a	70.00ab	70.00a
T7	50.00abc	46.67b	40.00b	56.67b	60.00ab	53.33b
T8	33.33cde	30.00cd	26.67cd	43.33bc	36.67cd	33.33cd
T9	26.67def	23.33d	23.33cd	36.67cd	30.00d	30de
T10	13.33fg	6.67e	10.00ef	30.00de	30.00d	10.00fg
T11(Control)	62.45a	66.47a	65.05a	80.00a	73.33a	73.33a
SE±	8.04	5.38	6.02	3.40	5.21	3.60
Significance	*	*	*	*	*	*
CV	28.69	20.57	24.06	9.53	12.90	10.31

**=significant at 5% level of significance, ns= non-significant at 5%level of significance NO= Neem oil, D= Detergent only, DAA=Day after application, Within parameters Means in a column followed by the same letter(s) are not significantly different at 5% level*

Table2.Effect of neem oil concentration treatments, frequency, and their interaction on foliar damage level at Jinka and Dassenach

Concentration	Foliar damage level at 42 DAA	
	Jinka	Dassenach
DO	3.77±0.30a	3.53±0.20a
NO 1%	1.93±0.17b	3.38±0.19a
NO 2%	1.38±0.16c	2.49±0.18b
NO 3%	1.37±0.17c	1.50±0.18c
Diazinon	0.28±0.18d	1.05±0.16c
Control	3.03±0.31a	4.71±0.20a
Significance	*	*
Frequency		
Weekly	1.51±0.10b	2.46±0.12a
Fortnightly	1.99±0.11a	2.32±0.10a
Significance	*	Ns
Concentration x Frequency		
T1	3.50±0.30a	3.45±0.26ab
T2	1.70±0.29bc	3.45±0.24b
T3	1.10±0.31c	2.19±0.25cd
T4	1.10±0.31c	1.50±0.25d
T5	0.13±0.30d	0.98±0.25d
T6	4.03±0.31a	3.61±0.26ab
T7	2.17±0.29b	3.30±0.25bc

T8	1.67±0.31bc	2.78±0.25bc
T9	1.63±0.29bc	1.50±0.25d
T10	0.43±0.31d	1.13±0.25d
T11(Control)	3.03±0.31a	4.17±0.25a
Significance	*	*
CV	20.18	15.19

*=significant at a 5% level of significance, ns= non-significant at 5%level of significance NO= Neem oil, DO= Detergent only; DAA=Day after application, within parameters Means in a column followed by the same letter(s) are not significantly different at 5% level

Table 3.Effect of neem oil concentration treatments, frequency, and their interaction on yield components and yield of maize

Concentration	Yield components and Yield of maize					
	Number of Cobplant-1		Cob length(cm)		Yield(kg/ha)	
	Jinka	Dassenech	Jinka	Dassenech	Jinka	Dassenech
DO	1.07a	1.03b	16.72a	14.75de	5150.9cd	3049.2c
NO 1%	1.10a	1.03b	16.83a	15.33cd	5683.6bc	3177.7 c
NO 2%	1.10a	1.03b	17.32a	15.96bc	6039.8abc	3355.3c
NO 3%	1.07a	1.10ab	17.40a	16.46ab	6349.3ab	3674.0b
Diazinon	1.17a	1.17a	17.33a	17.38a	6928.5a	4202.0a
Control	1.07a	1.00b	16.77a	13.83e	4513.8d	2718.7d
Significance	ns	*	Ns	*	*	*
Frequency						
Weekly	1.09a	1.08a	16.91a	15.79a	5924.3b	3542.3a
Fortnightly	1.107a	1.05a	17.33a	15.44a	5891.9a	3440.9b
Significance	ns	Ns	Ns	Ns	*	*
Concentration x Frequency						
T1	1.07a	1.00a	16.33b	15.00def	5245.8bcd	3107.0def
T2	1.07a	1.00a	16.93ab	15.41cde	5711.6abcd	3162.7def
T3	1.13a	1.07a	17.10ab	16.17abcd	6673.5a	3435.3cde
T4	1.07a	1.13a	17.37ab	16.83abc	6070.7ab	3614.3bc
T5	1.13a	1.13a	16.93ab	17.500a	5659.3ab	4273.0a
T6	1.07a	1.07a	16.97ab	14.5ef	5055.9cd	2991.3ef
T7	1.13a	1.00a	16.73ab	15.25def	5655.3abcd	3192.7def
T8	1.07a	1.00a	17.67a	15.75bcde	5835.8abcd	3275.3cde
T9	1.07a	1.07a	17.43a	16.08abcd	6060.3abcd	3733.7cd
T10	1.20a	1.20a	17.73a	17.25ab	6635.6a	4131.0ab
T11(Control)	1.07a	1.00a	16.77a	13.83f	4513.8c	2718.7f
SE±	0.088	0.06	0.499	0.42	594.73	139.93
Significance	ns	Ns	Ns	*	*	*
CV	9.77	6.53	3.57	3.28	9.03	5.10

*=significant at 5% level of significance, ns= non-significant at 5%level of significance, NO= Neem oil, DO= Detergent only, LSD=Least Significance Difference, SE=standard Error
Within parameters, Means in a column followed by the same letter(s) are not significantly different at a 5% level.

Effect of treatments on fall armyworm infestation

Considering Table 1, among neem oil concentration, plots treated with NO 3% caused the lowest percentage of plants infested at 14, 28, and 42 days after the first application followed by NO 2%, which was comparable to that of standard pesticide diazinon treated plot whereas, the highest percentage of plants infested were recorded from untreated control at Jinka location. At the dassanech location, NO 3% treated maize caused the lowest percent of infested plants at 14 and 28DAA, which was non-significant with standard pesticide diazinon-treated plots. At 42 DAANO 3% caused the lowest percentage of plants infested which was comparable to that of a standard pesticide diazinon-treated plot whereas, the highest percentage of infested plants was recorded from untreated control.

At the Jinka location, the frequency of application shows a significant effect on the percentage of plants infested. Treatment application every week records the lowest percent of infested plants at 28 DAA and on a fortnightly basis at 42 DAA. At the dassenech location, the percentage of the infested plant was significantly affected by the frequency of application 14 and 42 days after the first application ($p<0.05$)(Table 1). The lowest percentage of infested plants was recorded from the weekly application of concentrations.

There was a significant interaction effect between neem oil concentration and application frequency on fall armyworm infestation at the Jinka location ($p<0.05$).At 14 and 42 DAA, among neem oil concentrations, weekly applications of 2% and 3 %NO concentration caused the lowest percentage of infested plants, which is non-significant with fortnightly applications of 3% NO. The result recorded from 3%NO was comparable with the weekly application of standard insecticide Diazinon treated plot. At the Dassenech location, the lowest percentage of the infested plant was from the weekly application of diazinon-treated maize at 14 DAA. At 28 DAA, Weekly application of NO 3% causes the lowest percentage of infested plants, which was non-significant with weekly application of 2% NO. The result was comparable with weekly and fortnightly application of standard diazinon insecticide. At 14, 28, and 42 DAA, the highest percentage of infested plants was recorded from untreated control.

Above Table 2, NO 3% treated maize recorded the lowest leaf damage, which was the non-significant difference with NO 2%, treated maize. The result was comparable with standard pesticide diazinon-treated maize. The highest leaf damage was recorded from untreated control. Among frequency of application, weekly application of treatments records the lowest value of leaf damage, when compared to fortnightly application of treatments. There was a significant interaction effect between neem oil concentration and application frequency on maize foliar damage. Among neem oil concentrations the lowest leaf damage was recorded from weekly and fortnightly application of 3% neem oil followed by weekly and fortnightly application of 2% neem oil whereas, the highest leaf damage was recorded from untreated control. At Dassenech, the lowest leaf damage was recorded from diazinon insecticide-treated maize. Diazinon-treated maize was non-significant with NO 3% treated maize, whereas the highest leaf damage level was recorded from untreated maize. Among frequency of application, weekly application of treatments records the lowest percentage of infested plants at 42 days after the first application. There was a significant effect of interaction between neem oil concentration and application frequency on fall armyworm infestation ($p<0.05$). Weekly application of diazinon insecticide records the lowest foliar damage followed by weekly 3% NO concentration.

The current result is similar to the [37] research report that demonstrates neem oil (*Azadirachta indica*) can effectively control fall armyworm when applied in appropriate concentrations and intervals. Higher concentrations, such as 1–3%, and shorter application intervals of 7–10 days are most effective in reducing larval populations. Neem oil disrupts feeding, growth, and reproduction, aligning with integrated pest management principles. Despite challenges like labor intensity and environmental variability, neem oil enhances maize yield and reduces pest impact [38]. [41] reported that plants, that have pesticidal properties are effective for pest management through anti-feeding potential to insects. [30] reported that ingestion of the highest concentration (3.0v/v and 5.0% v/v) concentrations of the neem seed oil extracts resulted in 100% larval mortality in 6 hours after treatment. [35] reported that neem oil at the concentration of 1.40 L/ha at 7-day intervals was the most effective in reducing the incidence and the severity of the pests. [33] reported that synthetic insecticides have an anti-feeding effect causing early death of larvae and nymphs due to infestation and damage reduction due to inhibition of development and ecdysis defects; decreased food intake, and reduced pupal development.

The above Table 3 shows that neem oil concentration treatments have a significant effect on yield at the Jinka location (Table 2). The highest yield (6656.7kg/ha) was obtained from plot treated NO 2% followed by diazinon (6147.5kg/ha) and NO 3% (5951.7kg/ha). No Significant effect of application frequency on grain yield was observed. There was a significant interaction effect between neem oil concentration and application frequency on cob length and yield (Table 3). There was no interaction effect on the number of cobs per plant. The highest cob lengths 17.73, 17.67and 17.43 respectively were recorded from the fortnightly application of Diazinon 60 % EC at 1.5L/ha, NO2%, and NO 3% respectively. The highest (6673.5kg/ha, 6639.8kg/ha, and 6635.6kg/ha) grain yield was obtained from NO2% weekly and fortnightly application of Diazinon 60% EC, respectively. At Dassenech, Neem oil concentration treatments have a significant effect on the growth and yield of maize ($P<0.05$) (Table 2). The highest number of cob per plant and cob length was recorded from diazinon insecticide-treated maize followed by NO3% treated maize when compared with untreated maize which recorded the lowest value in all parameters. The highest grain yield was obtained from diazinon (4202.0 kg/ha) followed by NO3% (3674.0kg/ha).

A significant effect of application frequency on grain quality was observed. The highest yield (3542.3akg/ha) was obtained from weekly application of treatments. There was a significant interaction effect between neem oil concentration and application frequency on cob length, cob number, and grain yield (Table 3). The highest (4273.0kg/ha and 4131.0kg/ha) grain yield was obtained from weekly and fortnightly application of Diazinon 60% EC, respectively followed by weekly application of NO3% (3614.3kg/ha). In both locations, the lowest yield was recorded from the control plot. This could be due to the severity of fall army worm infestation. [14] Prasanna *et al*. (2018) reported that when fall armyworm occurred and untreated left resulting in severe infestation in the whole plant including cobs and other plant parts and yield reduction.

Conclusion and Recommendation

The fall armyworm is widely distributed all over the world as well as in Ethiopia, causing significant damage to maize. Using chemical pesticides to kill fall armyworms on maize plants by smallholder farmers of the study area has an indirect effect on health, environmental issues, and phytotoxicity on crops. Farmers have a lack of experience in the proper use of chemical pesticides which reflects the need to develop sustainable management options. Efforts should be made on comprehensive strategies combining cultural, botanical, biological, and chemical methods Enhanced farmer education, research on sustainable practices, and governmental support are critical to mitigating the pest's impact on agriculture and livelihoods. This study was conducted to evaluate and determine the effective concentration of neem oil and its application frequency for control of fall armyworm infestation and damage. Neem oil acts on insects by disrupting the pest's life cycle, providing an eco-friendly alternative to synthetic pesticides and enhancing maize productivity. From this study, higher concentrations (3%) and shorter intervals (weekly) are effective in reducing pest populations and minimizing crop damage. Lower concentrations may still provide some control but are less effective in FAW population reduction and minimizing crop damage. Weekly application of 3%NO spray is recommended for fall armyworm management on maize crops as an alternative to diazinon insecticides. For the future, the integration of effective neem oil concentration with other management methods is recommended for sustainable maize production. However, further research is needed to optimize its application for larger-scale use.

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Author contributions

Feyisa Bekele: Designed and conducted experiments, data collection, data Analysis, and manuscript writing**;** Wondimu Adila: Designed and conducted experiments, data collection, analysis, and manuscript writing**;** Kedir Bamud: Designed and conducted experiments and data collection; Yosef Berhun: Designed and Conducted experiment and data collection

Conflicts of interests

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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