



Spray Frequency Determination and Efficacy of Synthetic Insecticides against Pea Aphid (*Acyrtosiphon pisum*) on Lentil (*Lens culinaris*) in Central Highlands of North Shewa, Ethiopia

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Article history

Received: April 9, 2026

Revised: May 9, 2026

Accepted: July 30, 2026

Published: October 5, 2026

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E-ISSN and DOI

E-ISSN: 3026-2461

<https://doi.org/10.25077/aijent.4.2.87-98.2026>

ABSTRACT

The pea aphid (*Acyrtosiphon pisum* Harris) is one of the key pests of pulse crops worldwide. Improper selection and inappropriate use of insecticides are major constraints. A field experiment was conducted at the Enewari Burtilk research station during the 2021 and 2022 Main cropping seasons to determine the appropriate spray frequency and an effective insecticide for managing pea aphid on lentil. A factorial combination of four spray frequencies and three insecticides, including an untreated check, was laid out in a randomized complete block design with three replications. The application of Diemethoate 40% EC in combination with two spray frequencies at 7-day intervals revealed the lowest Pea aphid population, which in turn resulted in higher grain yield (1647 kg ha⁻¹), significant at *p* value < 0.05 than the untreated check (885 kg ha⁻¹), higher net benefit, MRR, and residual value. Application of Dimethoate at 150 l/ha in two sprays at 7-day intervals is effective and economical for managing pea aphid on lentil. Therefore, the application of 40% EC in combination with two sprays at 7-day intervals under high infestation, and, as an alternative, profenofos 72% with three sprays at 7-day intervals, with timely spraying under good weather conditions using factory recommendations, is effective for the management of pea aphid on lentil.

Keywords: *Acyrtosiphon pisum*, grain yield, lentil, spray frequency, systemic insecticide

INTRODUCTION

Lentil (*Lens culinaris* Medik.) is a high-value, profitable pulse crop if properly managed. Lentil is a major *rabi* pulse crop and is known for its protein-rich grains (Verma, 2025). World production was estimated at 3,590,000 metric tons per annum (Erskine *et al.*, 2011). Most of the production of lentils is done in the

developing world, approximately 75%. According to the reports by Rawal and Navarro (2019) and FAO (2021), Canada, India, Australia, and Turkey are the largest producers of lentil, accounting for 68% of global lentil production. In the 2019 season, Ethiopia alone produced 119,329 metric tons of lentil (FAOSTAT, 2019), making the country the top

producer in Africa. Lentil is one of the major highland pulses of Ethiopia, grown in rotation with tef, wheat, and barley, particularly on vertisols. It is an important part of the farming system and essential to nutrition in subsistence farming communities in Ethiopia. Lentils are an important source of protein and minerals, including iron, zinc, and beta-carotene, for both human consumption and animal feed. Lentil straw is a valuable feed for animals (Erskine *et al.*, 2016). Currently, lentil is considered a cash crop that fetches a higher price than most of the cereals and pulses (Abrham, 2015). Lentil is a main crop produced in the highlands of North Shewa. Among the districts, Moretina Jiru, Siyadebirna Wayu, and Ensaro Districts have high potential for the lentil crop. However, average yields have remained virtually static for various reasons.

The crop suffers substantial yield losses from various biotic and abiotic stresses. Among biotic factors, insect pests are major constraints on lentil productivity in Ethiopia. Foremost among insect pests, the pea aphid (*Acyrtosiphon pisum* (Harris)) is a regular pest that occurs in each growing season and sometimes causes total crop failures in lentil (Yadav *et al.*, 2007). Pea aphid (*Acyrtosiphon pisum*) infestations typically cause yield losses of about 5-15% in pulse crops globally, with specific studies reporting 4.6–12.5% losses in lentils in Morocco (El Fakhouri *et al.*, 2021). Data for East Africa are limited, but given similar agroecological conditions, losses in Ethiopia and neighboring countries are likely within this range.

The biology of *A. pisum* is a hemimetabolous insect with incomplete metamorphosis. The *A. pisum* undergoes both apomictic viviparous parthenogenesis and sexual reproduction, a phenomenon known as reproductive polyphenism. The *A. pisum* life cycle begins in the spring, when overwintered fertilized eggs hatch into a wingless fundatrix, which gives birth to nymphs (Schmidtberg & Vilcinskis, 2016). Following repeated cycles of asexual reproduction, the short days of autumn affect juvenile hormone production in aphid hemolymph, resulting in the production of a

parthenogenetic female. This female produces only one generation, which can consist of both wingless sexual females (oviparous) and winged and wingless males (Ogawa and Miura, 2013; Schmidtberg and Vilcinskis, 2016).

The host range of the pea aphid is mostly restricted to plants of the legume family. The pea aphid performs well on different cultivars of field pea, lentil, and faba bean. Field peas were infested until the time of flowering but recovered from the damage, and a normal yield was observed (Gavloski, 2018). (Wale *et al.*, 2003) said that high activity of *A. pisum* on pigeon pea, *Cajanus cajan* (L.) (Fabales: Fabaceae) Millsp from September to October in Ethiopia.

Surveys conducted in different lentil-growing areas of central Ethiopia by the Debre Zeit Agricultural Research Center (DZARC) between 1999 and 1994 confirmed the importance of this insect pest; later, comparisons were made between insecticide-treated and untreated plots, and they showed losses of 69 to 75% (Abrham, 2008). According to Gavloski (2018), *A. pisum* can cause economic losses in field peas, lentils, and sometimes faba beans. *Acyrtosiphon pisum* is a serious concern for commercial pulse producers because *A. pisum* can injure the crops directly by removing sap from leaves, stems, and pods, and indirectly by acting as a vector for over 30 plant viruses, including cucumber mosaic virus, beet yellows virus, pea enation mosaic virus, and bean leaf roll virus (Paudel *et al.*, 2018; Rashed *et al.*, 2018). The pea aphid usually attacks stems, terminal shoots, and petioles of seedlings, as well as flowers and pods. *Acyrtosiphon pisum* infests several host plants and causes chlorotic damage with curling and wilting of leaves, nutrient deficiencies, and plant stunting. Furthermore, by puncturing cells with their needle-like stylets, these aphids cause indirect, serious damage by injecting phytotoxic saliva (Wang *et al.*, 2017).

Different scientists in different situations suggest various management methods. Cultural control includes manuring to promote vigorous growth, crop rotation, manipulation of the

sowing date, mixed cropping, and field sanitation. Such practices may help reduce the population of harmful insects in the crop (Erkinse, 2009). Neem oil, garlic, and pepper extract generally proved effective in reducing pea aphid populations (Melaku, 2004), according to Getanh and Tebkew (2019). The application of Endosulfan 35% EC killed all aphids under laboratory conditions (Abebe, 2016). Primicarb insecticide generally proved effective in decreasing pea aphid population (Melaku, 2004). Farmers in North Shewa use Dimethoate, Endosulfan, and Diazinone insecticides to control pea aphid in lentil, but the last two are broad-spectrum (DBARC, 2017). Patil *et al.* (2014) reported that Imidacloprid 0.005% was the most effective against *A. Craccivora*. Patil *et al.* (2018) also opined that Dimethoate and Imidacloprid were quite promising in declining the population of cowpea aphid. Besides, Imidacloprid 17.8 SL @ 125 ml/ha and dimethoate 30 EC @ 750 ml/ha were selected as the best treatments for managing the population of *Aphis craccivora*. (Sheeren *et al.*, 2021). Rahman *et al.* (2023) again reported that insecticide treatments, including Profenophose, Dimethoate, Karate, Comander, and rotational applications, significantly reduced pea aphid populations compared to the control.

Farmers choose chemical insecticides over non-chemical methods for *A. pisum* control mainly due to the rapid response of chemical applications and their cost-effectiveness or economic benefit (Melaku, 2004). Until we develop an integrated management strategy, alternative synthetic insecticides are urgently needed, especially for aggressive pests such as the pea aphid. In addition, the application method, application frequency, and even the type of chemical to be applied must be considered with great care to ensure feasible economic gains and environmental safety. Most farmers in North Shewa apply synthetic insecticides without the guidance of agricultural experts.

The application of broad-spectrum insecticides leads to pest resurgence, the rapid reappearance of a pest population in injurious numbers. Besides, farmers in the study areas

apply at levels below and above the factory recommendations, i.e., dose, application frequency, and recommended interval. Improper or prophylactic insecticide applications can cause serious harm: they increase human health risks (acute poisoning, cancer, neurological disorders), damage ecosystems and accelerate pest resistance, making future control harder. Besides, frequent or unnecessary spraying accelerates the evolution of resistant pest populations. Once resistance develops, control becomes far more difficult and costly, often requiring stronger chemicals or entirely new strategies. Moreover, Overuse of insecticides can suppress the target pest but unintentionally allow other pest species to thrive. These secondary pests can become major problems, creating new cycles of infestation. Beneficial organisms such as predators, parasitoids, and pollinators are often more sensitive to insecticides than the pests themselves. Their removal destabilizes the ecosystem, reducing natural biological control and making pest outbreaks more severe. Hence, to fill this gap, selecting the best chemical insecticide and identifying the appropriate application frequency that yields the best economic return for lentil are important. Accordingly, the present investigation is proposed with the following objectives: To optimize spray frequency and to maximize economic returns while minimizing chemical inputs and ecological disruption.

METHODS

Study area description

The experiment was conducted at the Debre Birhan Agricultural Research Center (DBARC) Enewari research station during the main cropping seasons of 2021 and 2022. Burtilk is located in Moretena Jiru district (Figure 1). The research station is located at 9°52' North and 39°10' East at an altitude of 2680 m a.s.l., with a mean annual rainfall of 988mm. The average maximum and minimum temperatures of the area were 21.4 and 9.0°C, respectively. The soil type at the experimental site is classified as a vertisol with a clay loam texture.

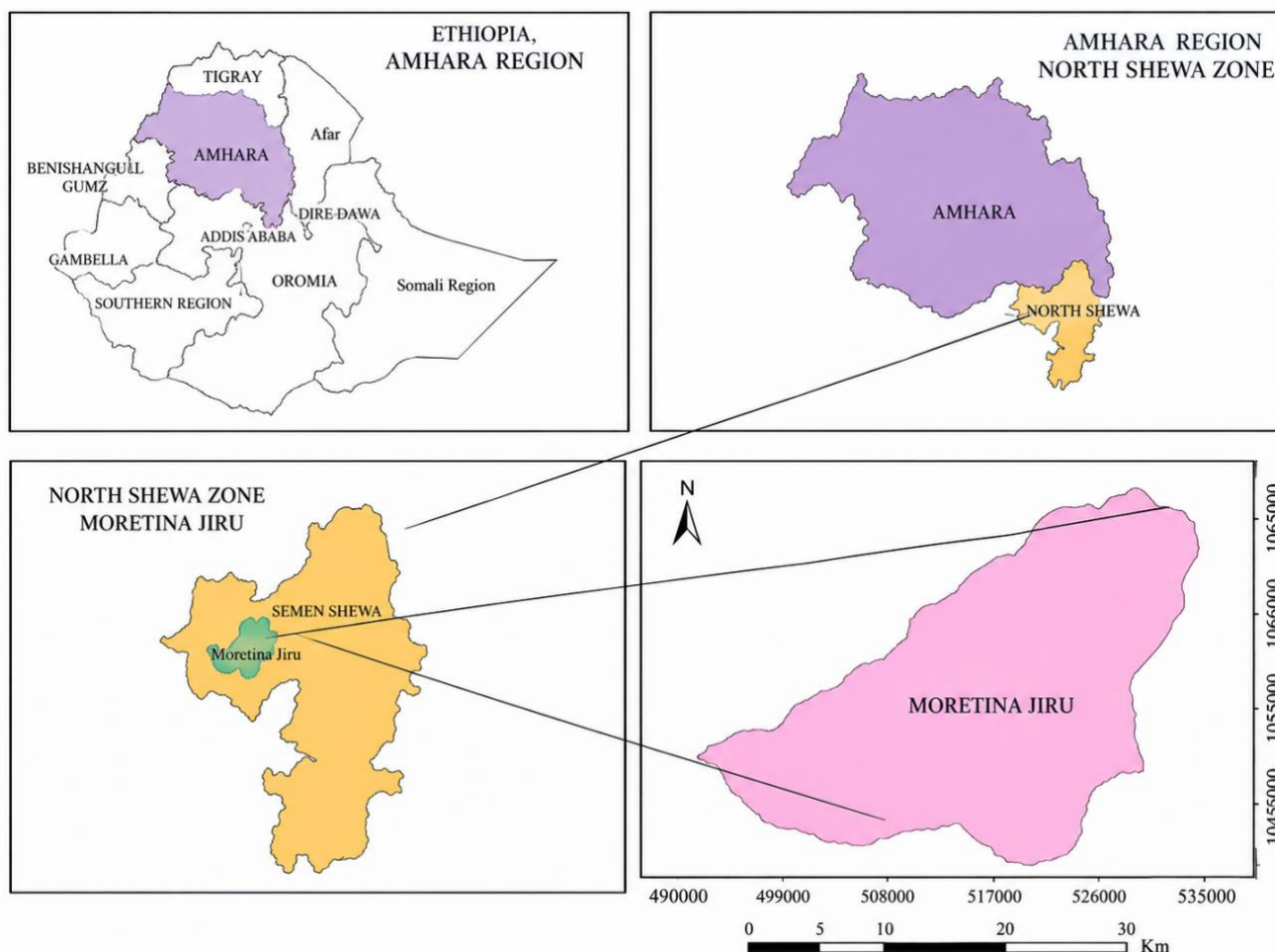


Figure 1. Map of the study area

Treatment application

The design of the experiment was a Randomized Complete Block Design (RCBD) with factorial arrangement in three replications. The lentil variety Derso was sown at a seed rate of 80 kg/ha, and NPS fertilizer was applied at 121 kg/ha. The plot size was 3 m*0.8 m (4 rows) at row spacing of 0.2m. The distance between plots and replication was 0.7m and

1.5m, respectively. A total of 13 plots, including the untreated control, were prepared for the experiment. The insecticides were formulated as per the factory recommendation: Profenofos 72% EC 0.75 lt/ha with 150 lt water/ha, Imidacloprid 350 SC at 400 ml/ha with 175 lt water/ha, and Dimethoate 40% Ec at a rate of 1 lt/ha with 150 lt water/ha, and applied using a knapsack sprayer while using a flat fan nozzle.

Table 1. General information about the insecticide

No	Common name	Trade Name	formulation	Mode of action
1	Diemethoate 40% EC	Ethiothoate 40% EC	Spray	Systemic
2	Profenofos 72% EC	Profit 72% EC	Spray	Semi-systemic
3	Imidacloprid 350SC	Confidence 350SC	Spray	Systemic

Treatment application was started at the threshold levels, when 23 aphids were found per 130 cm² area (Tebkew, 2017). The insecticides were evaluated four times throughout the growing season. The second,

third, and fourth applications were applied with 7-day intervals. Plastic barriers were installed in each plot to prevent insecticide drift during application. The time of application was determined by the day's wind and rainfall

conditions. All other agronomic activities, such as fertilizer application, seedbed preparation,

weeding, harvesting, threshing, and cleaning, were carried out as recommended.

Table 2. Treatment combination

Insecticides	Applications frequencies			
	Threshold (first spray)	7 days after the first spray	7 days after the second spray	7 days after the third spray
Diemethoate 40% EC	DXF1	DXF2	DXF3	DXF4
Profenofos72% EC	P X F1	P X F2	P X F3	P X F4
Imidacloprid 350SC	I XF1	IX F2	IX F3	C X F4

Note: F1 - F4 stands for the application frequency, F1 = applied one time, F2 = applied two times, F3 = applied three times, and F4 = applied four times, D = Diemethoate, P = Profenofos, and I = Imidacloprid

Data collection

The experimental plot monitoring began at seedling establishment to determine the onset of pea aphid invasion. Data collection was started when the average pea aphid population reached about 23 aphids per 130 cm² of the sampling board. Aphids were sampled by gently beating lentil plants onto a 20 cm by 39 cm counting board lined with a white plastic sheet. The board was subdivided into six 10 cm x 13 cm rectangles. At each sampling spot, pea aphids dislodged onto the counting board were counted from two randomly chosen rectangles. There were four sample spots per plot, where the average value was calculated (Tebkew, 2017). In addition, the following data were collected:

Number of aphids per 130 cm², 100 seeds weight in grams, Grain yield per hectare (GY), and Biomass per hectare (BMV)

Partial Budget Analysis

The adjusted yield was the average yield reduced by 10% to account for the difference between the experimental yield and the farmers' yield. Grain yield was the yield obtained per plot (in grams), converted to yield per hectare. Economic benefits of insecticide application were analyzed using the current prices of Lentil seed and straw yield (Birr/kg) assessed in the local market, and the total commodity price was then computed on a per-hectare basis at the time of harvesting. Input costs, such as insecticides and labor costs/ha,

were recorded. The cost of insecticides was calculated based on their prices and the number of applications used on a per-plot basis, and converted to hectares.

Data Analysis

Data collected from each year were analyzed to assess the insecticide efficacy. These data were examined with a generalized linear mixed-effect model. Data were analyzed in RStudio version 4.4.0 with the packages "lme" (Bates et al., 2015) and "emmeans" (Lenth, 2021). Mean comparisons for treatment parameters were conducted using the least significant difference test at the 5% significance level.

RESULTS AND DISCUSSION

Effect of treatments on biomass yield, grain yield, and hundred-seed weight

The present study revealed that treatments P*F1 (2089), I*F2 (3364), D*F3 (3482), and P*F4 (3602) showed significant differences ($P < 0.05$) in aboveground biomass yield (Table 3). Grain yield, in kilograms per hectare, ranged from 885 to 1647 among treatments. Similarly, even if there is no significant difference in grain yield within the same insecticide in each frequency, there is a significant effect among treatments at ($P < 0.05$) D*F2 (1647), P*F4 (1588), and P*F3 (1525) on grain yield than I*F3 (1020) and the untreated control. Hundred-seed weight showed significant differences ($P < 0.05$) among treatments, ranging from 2.5g (untreated control) to 3.1g (P*F3) (Table 3).

Table 3. Combined effect of insecticides and frequency of application on Grain yield and hundred-seed weight of lentil

Treatments	Biomass yield (kg ha ⁻¹)	Grain yield (kg ha ⁻¹)	100 seeds weight (g)
D*F1	2827ab	1230abc	2.8ab
D*F2	3048ab	1647a	2.9ab
D*F3	3482a	1479ab	2.9ab
D*F4	3166ab	1318abc	2.8ab
P*F1	2089b	1365abc	2.8ab
P*F2	3153ab	1458ab	2.8ab
P*F3	2693ab	1525a	3.1a
P*F4	3602a	1588a	2.8ab
I*F1	2587ab	1135b	2.6ab
I*F2	3364a	1117b	2.6ab
I*F3	2601ab	1020bc	2.9ab
I*F4	3009ab	1095bc	2.7ab
Untreated	3144ab	885c	2.5b
mean	2982	1297	3
CV%	21	20	8.7
Sig	*	*	*

Note: D = Dimethoate, P = Profenofos, I = Imidacloprid F1 to F4 = Frequency of application

Means with the same letter(s) in the columns and rows are not significantly different at $p < 5\%$ level of significance, CV (%) = Coefficient of variation, NS = non-significant, * = Significant difference at $p < 5\%$

Effect of synthetic insecticides and frequency of spray on aphid population

The recorded pea aphid population count indicated that the maximum number of pea aphids was attained in all treatments at the threshold (before the first spray). **Clearly**, there was no significant difference in terms of aphid counts. Aphid population was higher with Imidacloprid at application frequencies of 1 to 4 and was significantly lower than in the untreated plots ($P < 0.001$). However, after treatment, aphid populations were reduced due to insecticide application. The effectiveness of these insecticides varied with increased application frequencies. From the economic point of view, the best application frequency was Dimethoate 40 % EC two times spray which is significantly different ($P < 0.001$) in pea aphid population reduction (0.1) (DASS) days after second spray this result is in line with (Mintesnot, 2017) early sowing plus two foliar application of Dimethoate, harbored significantly lower aphid population below its action threshold level (7.67 plant⁻¹). In line with the present study, Sheeren *et al.* (2021) also

reported that, at 7 DAS after spraying, the lowest number of pea aphids per plant was observed in the dimethoate 30 EC treatment @ 750 ml/ha (12.06 aphids/plant). Next to Dimethoate, profenofos 72% EC followed with pea aphid count (1.2) attained after 3 days of the third (DATS) spray, which is better than Imidacloprid and control. The observed difference could be due to the chemical effects (Figure 2).

The experiment showed that proper use of insecticides and appropriate application frequency are safe for the environment and hinder insecticide resistance. This result is consistent with the decrease in spray frequency, which may suppress the evolution of resistance (Kohji, 2021). Similarly, Dagne and Lemma (2022) noted that, along with increased pesticide use and unsafe management, there is growing concern that the risks and negative impacts of these chemicals on human and animal health, as well as the environment, have also been increasing in Ethiopia. Dimethoate and rotational application were particularly effective, supporting previous research on pest

monitoring and resistance management (Siddiqui *et al.*, 2022). The rotation of insecticides with varying modes of action is a

tried-and-true way to slow the development of resistance in insect populations by reducing selection pressure (Siddiqui *et al.*, 2022).

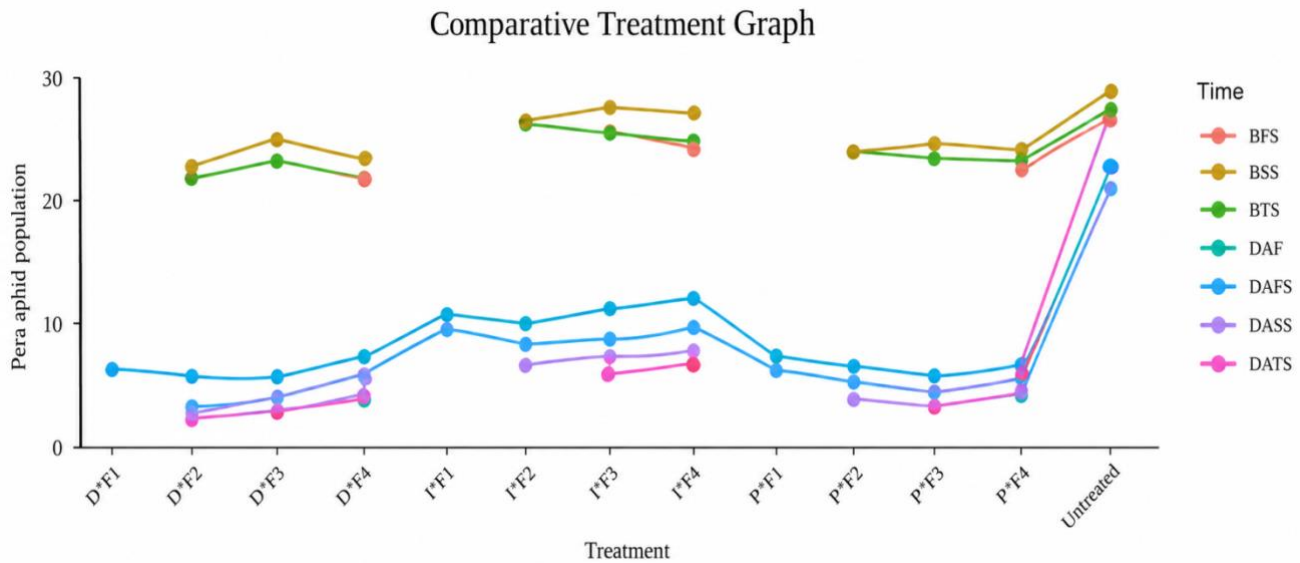


Figure 2. Effect of insecticides and spray frequency on aphid population.

Note: DAFS = Days after first Spray, BSS = Before second spray, DASS = Days after second spray, BTS = Before third spray, DATS = Days after third spray, BFS = Days before fourth spray, and DAF = Days after fourth spray, D= Dimethoate 40%EC, I=Imidacloprid 350 SC, P= Profinofos 72%, F1-F4 =Frequency of spray

Effect of weather parameters on the development and survival of the pea aphid

The pea aphid population recorded in each treatment indicated that the aphid population was higher in all treatments at threshold (before spray) when the average maximum temperature in the study area ranged from 20.6 in August to 20.3 in September, which favors the biology of the pea aphid. Hence, the aphid population began to increase as the maximum temperature rose (Figure 3). This result is consistent with Wale *et al.* (2000), who reported that 18-24°C is the optimum temperature for *A. pisum* growth and development, and that the intrinsic rate of increase was highest at 22°C in Ethiopia.

Aphids are poikilothermic organisms; their development is mainly influenced by

temperature (Bale *et al.*, 2002). These insects can respond to an increase in temperature by faster development (Mehrparvar & Hatami, 2007; Borowiak & Durak, 2012), increased reproduction (Bale *et al.*, 2002), higher winter survival (Kiritani, 2006), changes in life cycles (Margaritopoulos, 2002), changes in migration timing (Hullé *et al.*, 2010; Danks, 2007), or changes in the dynamics of populations (Yamamura, 2006). Rainfall negatively affected the aphid population: when rainfall decreased, the aphid population increased. However, rainfall helps the host plant retain juicy sap and soften the tissue, as supported by Clement *et al.* (2010). Clearly, rainfall in both winter and spring is important for moisture maintenance in host plants, which influences *A. pisum* population development.

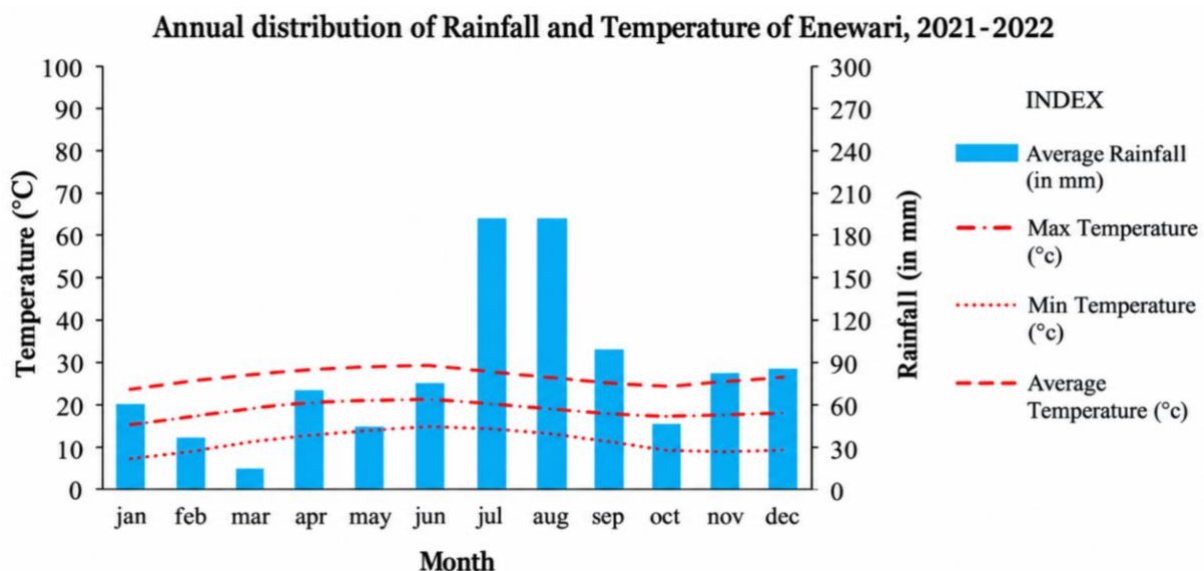


Figure 3. Annual Distribution of Rainfall and Temperature

Source: <https://power.larc.nasa.gov/data-access-viewer/>

Correlation of pea aphid counts at the threshold with maximum and minimum temperatures showed positive, significant correlations ($r = 0.99$ and 0.9 , respectively). Besides, the maximum temperature showed a positive and significant correlation with the aphid population days after the spray ($r=0.9$), before the second spray ($r=0.97$), and days after the second spray ($r=0.84$). Similarly, a positive and significant correlation was observed between each spray frequency and the minimum temperature ($r = 0.74$ to 0.9). Maximum temperature is strongly associated with aphid population buildup; rising global temperatures under climate change scenarios could further increase aphid

vulnerability. At suitable temperatures, they develop faster. Increased temperatures will accelerate the development of these insect types, leading to more generations per year (Awmack *et al.*, 1997). This may necessitate revisiting the current 7-day spray interval recommendation, with shorter intervals or adaptive strategies becoming increasingly important in warmer conditions. At the same time, rainfall showed a negative, non-significant correlation at the threshold ($r = -0.1$) and days after spray ($r = -0.39$). In addition, rainfall showed a negative, non-significant correlation before the second spray ($r = -0.25$) and days after the second spray ($r = -0.45$) during 2021 and 2022 (Table 4).

Table 4. Correlation of Pea aphid counts in relation to weather parameters

Time of aphid count	Max. Tem	Min. Tem	Rainfall
Tresh hold	0.99*	0.9*	-0.1
DAFS	0.90*	0.84*	-0.39
BSS	0.97*	0.96*	-0.25
DASS	0.84*	0.74*	-0.45

Note: * = Significant at 5% level of significance, DAFS = Days after first spray, BSS = Before second spray, and DASS = Days after second spray

Partial budget analysis

Dominance analysis was conducted as a prerequisite for further economic analysis to identify the dominated treatments for which net benefit decreased while the cost that varies

increased (Table 5). I*F1, I*F2, I*F3, I*F4, P*F1, P*F2, D*F1, D*F3, and D*F4 dominated, as their costs were higher than the previous one and their net benefits were higher. Hence, these treatments would be excluded from further analysis.

Table 5. Partial Budget analysis for insecticides and frequency of spray

Treatment	Y (kg ha ⁻¹)	Adj.Y(Kg ha ⁻¹)	Gross benefit (ETBha ⁻¹)	TVC (ETB/ha ⁻¹)	NB (ETB/ha ⁻¹)	MRR %
untreated	885	796.5	31860	0	31860	
I*F1	1135	1021.5	40860	1100	39760 D	
I*F2	1117	1005.3	40212	1200	39012 D	
P*F1	1365	1228.5	49140	1240	47900 D	
I*F3	1020	918	36720	1300	35420 D	
P*F2	1458	1312.2	52488	1340	51148 D	
D*F1	1230	1107	44280	1350	42930 D	
D*4	1318	1186	47200	1400	45800	
I*F4	1095	985.5	39420	1400	38020 D	
P*F3	1525	1372.5	54900	1700	53500	1272
D*F2	1647	1482.3	59292	2100	57192	1206
P*F4	1588	1429.2	73106	2150	53168	991
D*F3	1479	1331.1	53244	2200	51044 D	

Note: D = Diemethoate, P = Profenofos, I = Imdacloprid, F1 to F4 = Frequency of application, Y = Lentil seed yield, Adj Y.= Adjusted yield, TCV = Total Cost that varies, NB = Net benefit from grain and straw, MRR = Marginal rate of return.

Diemethoate 40% EC at application frequency 2, followed by profit 72% EC at frequency 3, provides a higher net benefit of 57192 and a marginal rate of return (MRR) of 1206 than the other treatments. This result is in line with Mintesenot (2017), who found that a lentil sprayed with 40% EC Diemethoate at 1.5 lt/ha⁻¹ was effective in reducing the aphid population below its action threshold.

The study highlighted important discrepancies between the technical and economic optimum, as the yield and return of lentil were high for D*F2 (Dimethoate spraying twice). In comparison, the next-best treatment for net benefit was P*F3 (Profenofos 72 % EC spraying three times), with net benefit (53500) and 1272 (MRR).

CONCLUSIONS

Application of Diemethoate 40% EC in combination with two times spray at 7 days interval was well effective, invite the lowest number of pea aphid population plus it provides maximum grain yield and marginal rate of return (MRR), net benefit and residual value this also highlighted the importance of residual effect related to the insecticides and spray

frequencies alternatively profenofos 72% three times spray at 7 days interval result in declining pea aphid population and economically feasible. Moreover, farmers in the study areas sprayed Diazinon 40% EC and profenofos 72% EC repeatedly at improper doses and application frequencies, even within 5-day intervals, more than 4 times, which was not economically viable and can cause serious harm, including human health risks and damage to ecosystems. So it enables farmers to abandon such improper doses and application frequencies. Therefore, the application of 40% EC in combination with two sprays at 7-day intervals under high infestation, and, as an alternative, profenofos 72% with three sprays at 7-day intervals, spraying timely with good weather conditions using factory recommendations, is effective for the management of pea aphid on lentil.

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