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OPTIMIZATION OF UAV-BASED INSECTICIDE APPLICATION FOR EFFECTIVE MANAGEMENT OF FALL ARMYWORM AND STEM BORER IN MAIZE

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ABSTRACT

Maize (*Zea mays* L.) is one of the most important cereal crops worldwide; however, its productivity is severely affected by insect pests, particularly fall armyworm (*Spodoptera frugiperda* J.E. Smith) and stem borer (*Chilo partellus* Swinhoe). Efficient pesticide application through Unmanned Aerial Vehicles (UAVs) has emerged as a promising alternative to conventional spraying by improving spray coverage while reducing labour and water requirements. The present investigation was conducted during Kharif 2025–26 at the Main Agricultural Research Station, University of Agricultural Sciences, Dharwad, Karnataka, to optimize insecticide dose and spray volume for UAV-assisted management of major maize insect pests. The experiment was laid out in a Randomized Block Design comprising fifteen treatments with two replications. Chlorantraniliprole 18.5% SC and spinetoram 11.7% SC were evaluated at different doses using UAV spray volumes of 20 and 30 L ha⁻¹ and compared with conventional knapsack spraying (500 L ha⁻¹). Two insecticide applications were imposed at the economic threshold level, and observations on larval population of fall armyworm, pin-hole damage caused by stem borer, grain yield and economics were recorded. Among all the treatments, chlorantraniliprole 18.5% SC applied at 200 ml ha⁻¹ through UAV with a spray volume of 30 L ha⁻¹ consistently recorded the lowest fall armyworm population (1.39 larvae plant⁻¹) with 81.19 per cent reduction over control and the lowest stem borer damage (0.98 damaged leaves plant⁻¹) with 87.04 per cent reduction over control. The same treatment also produced the highest grain yield (38.8 q ha⁻¹), gross returns (₹ 1,16,400 ha⁻¹), net returns (₹ 56,600 ha⁻¹) and benefit:cost ratio (1.95). UAV application with 30 L ha⁻¹ spray volume consistently outperformed 20 L ha⁻¹ spray volume and conventional knapsack spraying owing to better canopy penetration, improved spray deposition and enhanced biological efficacy. The study demonstrated that chlorantraniliprole 18.5% SC applied at 200 ml ha⁻¹ through UAV with a spray volume of 30 L ha⁻¹ provides an efficient, economical and sustainable operational protocol for precision management of major insect pests of maize.

Key words : Maize, Unmanned aerial vehicle (UAV), Chlorantraniliprole, Spinetoram, *Spodoptera frugiperda*, *Chilo partellus*, Precision agriculture.

Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops cultivated worldwide and serves as a major source of food, feed and industrial raw materials. In India, maize is cultivated over diverse agro-climatic regions and contributes significantly to food security, livestock

production and the starch industry. However, its productivity is frequently constrained by insect pests, among which the fall armyworm, *Spodoptera frugiperda* (J.E. Smith), and the spotted stem borer, *Chilo partellus* (Swinhoe), are the most destructive. Since its first report in India during 2018, fall armyworm

has spread rapidly across major maize-growing states and has become a serious threat because of its high reproductive capacity, migratory behaviour, wide host range and ability to develop resistance to insecticides (Goergen *et al.*, 2016; Ganiger *et al.*, 2018; Sharanabasappa *et al.*, 2018; Deshmukh *et al.*, 2020). Severe infestations of fall armyworm may result in yield losses ranging from 20 to 70 per cent depending on crop stage, pest density and environmental conditions, while stem borer infestation causes characteristic pin-hole damage, dead hearts and reduction in grain yield (Day *et al.*, 2017; Prasanna *et al.*, 2022).

Chemical control remains one of the most effective components of integrated pest management for both fall armyworm and stem borer because of its rapid action and ability to prevent severe crop damage when applied at the appropriate crop stage. Among the recommended insecticides, chlorantraniliprole and spinetoram have shown excellent efficacy against lepidopteran pests owing to their novel modes of action, high biological activity and favourable environmental profile (Cordova *et al.*, 2006; Sparks *et al.*, 2008). Nevertheless, the effectiveness of these insecticides depends largely on the efficiency of spray application, which determines the quantity of insecticide deposited on the target plant surfaces and feeding sites of the insect.

Conventional pesticide application using knapsack or tractor-mounted sprayers is often associated with high water consumption, labour scarcity, uneven spray distribution, crop trampling and greater exposure of spray operators to pesticides. In recent years, Unmanned Aerial Vehicle (UAV)-based spraying has emerged as an efficient precision agriculture technology capable of overcoming many of these limitations. UAV applicators enable rapid and uniform pesticide application with reduced spray volume, lower labour requirement, minimal crop damage and improved field efficiency. In addition, the rotor-generated downwash produced by UAVs enhances droplet penetration into dense crop canopies, resulting in improved spray deposition on concealed target sites where insect pests commonly occur (Qin *et al.*, 2016; Tang *et al.*, 2021; Shan *et al.*, 2022).

The success of UAV-based pesticide application depends not only on the insecticide used but also on optimization of operational parameters such as spray volume, application rate, nozzle characteristics and flight parameters. Spray volume is particularly important because it influences droplet density, canopy coverage, retention and biological efficacy. Inadequate spray volume may reduce insecticide deposition and pest mortality, whereas excessive spray volume increases operational

costs, pesticide wastage and environmental contamination. Therefore, optimization of insecticide dosage and spray volume is essential to maximize pest control efficiency while minimizing pesticide input and production costs (Shan *et al.*, 2022; Liu *et al.*, 2025).

Although, UAV technology is increasingly being adopted for crop protection, information on optimum insecticide dosage and spray volume for effective management of major insect pests of maize under Indian field conditions is still limited. Therefore, the present investigation was undertaken to optimize insecticide dosage and spray volume for UAV application of chlorantraniliprole 18.5 SC and spinetoram 11.7 SC against fall armyworm and stem borer in maize. The findings are expected to provide scientifically validated recommendations for efficient UAV-assisted pesticide application, thereby improving pest management, enhancing productivity and promoting sustainable maize cultivation.

Materials and Methods

Experimental site

The field experiment was conducted during *Kharif* 2025–26 at the Main Agricultural Research Station (MARS), University of Agricultural Sciences, Dharwad, Karnataka, India (15°26' N latitude, 75°07' E longitude and 678 m above mean sea level). The study was undertaken to optimize insecticide dose and spray volume for Unmanned Aerial Vehicle (UAV)-based application against major insect pests of maize under field conditions.

Experimental details

The experiment was laid out in a Randomized Block Design (RBD) comprising 15 treatments with two replications. Maize hybrid ANKUR BHANU was sown at a spacing of 60 × 20 cm in plots measuring 50 × 20 m. The crop was raised by following the recommended package of practices of the University of Agricultural Sciences, Dharwad, except for insecticidal treatments. Farmyard manure at 1 t ha⁻¹, vermicompost at 2.5 t ha⁻¹ and fertilizers at the rate of 150:65:65 kg N:P₂O₅:K₂O ha⁻¹ were applied as per the recommended agronomic practices.

Insecticide treatments and spray application

The experiment comprised 15 treatments, including two insecticides, chlorantraniliprole 18.5% SC and spinetoram 11.7% SC, evaluated at different dosages and spray volumes using an Unmanned Aerial Vehicle (UAV). Chlorantraniliprole 18.5% SC was evaluated at 200, 150 and 100 ml ha⁻¹ using UAV spray volumes of 20 and 30 L ha⁻¹, while chlorantraniliprole 18.5% SC applied at 200

ml ha⁻¹ through a knapsack sprayer with a spray volume of 500 L ha⁻¹ served as the standard check. Similarly, spinetoram 11.7% SC was evaluated at 250, 187.5 and 125 ml ha⁻¹ using UAV spray volumes of 20 and 30 L ha⁻¹, whereas spinetoram 11.7% SC applied at 250 ml ha⁻¹ through a knapsack sprayer with a spray volume of 500 L ha⁻¹ served as the standard check. An untreated control was maintained for comparison. Thus, the experiment consisted of six chlorantraniliprole treatments under UAV application, six spinetoram treatments under UAV application, two conventional knapsack spray treatments and one untreated control. The details of the treatments are presented in Table 2.

The insecticides were applied using a battery-operated hexacopter UAV equipped with flat fan nozzles. Spraying was carried out according to the Standard Operating Procedures (SOPs) prescribed by the Ministry of Agriculture and Farmers Welfare, Government of India, for agricultural drone operations. During spraying, the UAV was operated at a flight height of 2.0 m above the crop canopy, a forward flight speed of 4.5–5.0 m s⁻¹ and an effective swath width of 3.5–4.0 m to ensure uniform spray coverage. Spray volume was calibrated before each application to deliver the desired quantity of insecticide accurately.

Two insecticide applications were imposed during the crop season. The first spray was applied at 20–25 days after sowing (DAS), when the incidence of fall armyworm and stem borer reached the economic threshold level. The second spray was given 15–20 days after the first application, depending on pest incidence. All spraying operations were carried out during the early morning hours under favourable weather conditions, with wind velocity below 10 km h⁻¹, temperature between 25 and 30°C and relative humidity ranging from 60 to 80% to minimize spray drift and enhance droplet deposition.

Before each spray, the UAV delivery system was calibrated to ensure uniform discharge rate, nozzle output and spray distribution. The required quantity of insecticide was mixed thoroughly with clean water to prepare the spray solution according to the respective treatment. The spray tank was agitated continuously during operation to maintain uniform suspension of the insecticide. Conventional knapsack spraying was performed using a manually operated lever-operated knapsack sprayer fitted with a hollow cone nozzle and calibrated to deliver 500 L ha⁻¹ spray solution. Care was taken to avoid spray drift between adjacent plots by maintaining adequate buffer zones and spraying under calm weather conditions.

Recording of observations

Fall armyworm : The larval population of *Spodoptera frugiperda* was recorded by counting the number of larvae per plant from five randomly selected and tagged plants in each plot. Observations were recorded one day before spraying (1 DBS) and at 1, 3, 7 and 10 DAS after each spray (DAS).

Stem borer : The incidence of *Chilo partellus* was assessed by recording the number of leaves showing pin-hole damage per plant from the same tagged plants. Observations were recorded at 1 DBS and at 1, 3, 7 and 10 DAS after each insecticide application.

Grain yield : The crop was harvested at physiological maturity and grain yield from each net plot was recorded and converted into quintals per hectare (q ha⁻¹).

Statistical analysis

The experimental data were subjected to analysis of variance (ANOVA) appropriate for a Randomized Block Design (RBD). Count data on larval population and pin-hole damage were subjected to square-root transformation [$\sqrt{(x + 0.5)}$] before analysis wherever necessary. Treatment means were compared using Duncan's Multiple Range Test (DMRT) at the 5 per cent probability level. Statistical analysis was carried out using OPSTAT statistical software.

Economic analysis

The economics of different treatments were computed based on the prevailing market prices of maize grain, insecticides and application charges. Gross returns, net returns and benefit:cost ratio were calculated using the following equations:

- Cost of cultivation (₹ ha⁻¹) = Cost of cultivation + Cost of insecticide + Cost of application
- Gross returns (₹ ha⁻¹) = Grain yield × Market price of maize
- Net returns (₹ ha⁻¹) = Gross returns – Total cost of cultivation
- Benefit:Cost ratio = Gross returns ÷ Total cost of cultivation

Results and Discussion

Bio-efficacy of recommended insecticides against fall armyworm, *Spodoptera frugiperda* during Kharif 2025–26

The efficacy of recommended insecticides applied through an unmanned aerial vehicle (UAV) at different spray volumes against fall armyworm, *Spodoptera frugiperda*, was evaluated by recording larval population

before and after two sequential insecticide applications. The results are presented in Table 1. The pre-treatment observations recorded one day before the first and second sprays (1 DBS) were non-significant, indicating uniform infestation of fall armyworm among all the treatments before insecticide application.

Following the first spray, significant differences among the treatments were observed from one day after spraying (1 DAS) onwards. Among all the treatments, chlorantraniliprole 18.5% SC applied at 200 ml ha⁻¹ through UAV with a spray volume of 30 L ha⁻¹ (T₄) recorded the lowest larval population throughout the observation period, with 1.67, 1.06, 0.35 and 0.23 larvae plant⁻¹ at 1, 3, 7 and 10 DAS, respectively. The treatment was statistically superior to all other treatments and was closely followed by spinetoram 11.7% SC applied at 250 ml ha⁻¹ through UAV with a spray volume of 30 L ha⁻¹ (T₁₁), which recorded 1.76, 1.14, 0.45 and 0.24 larvae plant⁻¹ at the corresponding observation periods. Chlorantraniliprole 18.5% SC applied at 200 ml ha⁻¹ through UAV with 20 L ha⁻¹ spray volume (T₁) also provided effective suppression by recording 1.84, 1.24, 0.54 and 0.32 larvae plant⁻¹ during the first spray observations.

A similar trend was observed following the second spray. Chlorantraniliprole 18.5% SC applied at 200 ml ha⁻¹ through UAV with a spray volume of 30 L ha⁻¹ (T₄) continued to record the lowest larval population, with only 1.56, 0.95, 0.33 and 0.12 larvae plant⁻¹ at 1, 3, 7 and 10 DAS, respectively. This treatment was followed by chlorantraniliprole 18.5% SC applied at 200 ml ha⁻¹ through UAV with 20 L ha⁻¹ spray volume (T₁), which recorded 1.83, 1.04, 0.34 and 0.22 larvae plant⁻¹, while spinetoram 11.7% SC applied at 250 ml ha⁻¹ through UAV with 30 L ha⁻¹ spray volume (T₁₁) recorded 1.85, 1.16, 0.44 and 0.24 larvae plant⁻¹. The second spray further reduced larval populations across all treatments, indicating effective suppression of surviving larvae and newly emerging infestations through sequential insecticide applications.

The pooled mean values clearly demonstrated the superiority of chlorantraniliprole applied through UAV with a spray volume of 30 L ha⁻¹. Chlorantraniliprole 18.5% SC applied at 200 ml ha⁻¹ with 30 L ha⁻¹ spray volume (T₄) recorded the lowest pooled mean larval population (1.39 larvae plant⁻¹) and the highest reduction over control (81.19%). This was followed by spinetoram 11.7% SC applied at 250 ml ha⁻¹ through UAV with 30 L ha⁻¹ spray volume (T₁₁), which recorded a pooled mean larval population of 1.55 larvae plant⁻¹ with 79.01 per

cent reduction over control. Chlorantraniliprole 18.5% SC applied at 200 ml ha⁻¹ through UAV with 20 L ha⁻¹ spray volume (T₁) also recorded excellent control, with a pooled mean larval population of 1.52 larvae plant⁻¹ and 79.42 per cent reduction over control.

Among the intermediate dose treatments, chlorantraniliprole applied at 150 ml ha⁻¹ through UAV with 30 L ha⁻¹ spray volume (T₅) recorded a pooled mean larval population of 1.57 larvae plant⁻¹ and 78.76 per cent reduction over control, whereas the corresponding treatment with 20 L ha⁻¹ spray volume (T₂) recorded a pooled mean of 1.67 larvae plant⁻¹ and 77.39 per cent reduction over control. Similarly, spinetoram applied at 187.5 ml ha⁻¹ through UAV with 30 L ha⁻¹ spray volume (T₁₂) recorded a pooled mean of 1.76 larvae plant⁻¹, while the corresponding treatment with 20 L ha⁻¹ spray volume (T₉) recorded a pooled mean of 1.90 larvae plant⁻¹.

Lower insecticide dosages resulted in comparatively higher larval populations irrespective of spray volume. Chlorantraniliprole applied at 100 ml ha⁻¹ through UAV with 30 L ha⁻¹ spray volume (T₆) recorded a pooled mean of 1.81 larvae plant⁻¹ with 75.50 per cent reduction over control, whereas the corresponding treatment with 20 L ha⁻¹ spray volume (T₃) recorded a pooled mean of 1.93 larvae plant⁻¹ and 73.87 per cent reduction over control. Likewise, spinetoram applied at 125 ml ha⁻¹ through UAV with 30 L ha⁻¹ spray volume (T₁₃) recorded a pooled mean of 2.10 larvae plant⁻¹, whereas the corresponding treatment with 20 L ha⁻¹ spray volume (T₁₀) recorded the highest pooled mean larval population (2.20 larvae plant⁻¹) among the UAV treatments.

The conventional knapsack applications were comparatively less effective than the corresponding UAV applications. Chlorantraniliprole applied through a knapsack sprayer (T₇) recorded a pooled mean larval population of 2.11 larvae plant⁻¹ with 71.43 per cent reduction over control, while spinetoram applied through a knapsack sprayer (T₁₄) recorded a pooled mean of 2.21 larvae plant⁻¹ with 70.08 per cent reduction over control. In contrast, the untreated control exhibited a rapid increase in larval population after both sprays, recording 12.64 larvae plant⁻¹ at 10 DAS following the first spray and 10.44 larvae plant⁻¹ after the second spray, resulting in the highest pooled mean larval population of 7.39 larvae plant⁻¹.

The results clearly demonstrated that UAV application with a spray volume of 30 L ha⁻¹ consistently provided superior control of fall armyworm compared with 20 L ha⁻¹ spray volume and conventional knapsack spraying. The higher spray volume likely enhanced droplet

Table 1 : Bio-efficacy of recommended insecticides against fall armyworm, *Spodoptera frugiperda* in maize during Kharif 2025-26.

S. no.	Treatment details	Dose (ml/ha)	Spray equipment	No. of larvae/ plant												%ROC	
				First Spray						Second Spray							Mean
				1 DBS	1 DAS	3 DAS	7 DAS	10 DAS	1 DBS	1 DAS	3 DAS	7 DAS	10 DAS				
1	Chlorantraniliprole 18.5% SC	200	20 (Drone)	4.83 (2.31)	1.84 (1.53) ^c	1.24 (1.32) ^f	0.54 (1.02) ^f	0.32 (0.91) ^c	4.43 (2.22)	1.83 (1.53) ^b	1.04 (1.24) ^a	0.34 (0.91) ^b	0.22 (0.85) ^a	1.52	79.42		
2	Chlorantraniliprole 18.5% SC	150	20 (Drone)	4.72 (2.29)	1.96 (1.57) ^e	1.43 (1.39) ^f	0.76 (1.12) ^f	0.53 (1.01) ^c	4.56 (2.25)	2.05 (1.60) ^d	1.26 (1.33) ^c	0.55 (1.02) ^f	0.33 (0.91) ^c	1.67	77.39		
3	Chlorantraniliprole 18.5% SC	100	20 (Drone)	4.89 (2.32)	2.07 (1.60) ^b	1.78 (1.51) ^b	1.05 (1.25) ^b	0.82 (1.15) ^b	4.67 (2.27)	2.36 (1.69) ^b	1.67 (1.47) ^b	0.76 (1.12) ^b	0.55 (1.02) ^b	1.93	73.87		
4	Chlorantraniliprole 18.5% SC	200	30 (Drone)	4.76 (2.29)	1.67 (1.47) ^a	1.06 (1.25) ^a	0.35 (0.92) ^f	0.23 (0.85) ^a	4.35 (2.20)	1.56 (1.44) ^a	0.95 (1.20) ^a	0.33 (0.91) ^a	0.12 (0.79) ^a	1.39	81.19		
5	Chlorantraniliprole 18.5% SC	150	30 (Drone)	4.84 (2.31)	1.87 (1.54) ^d	1.28 (1.33) ^d	0.57 (1.03) ^d	0.34 (0.91) ^d	4.46 (2.23)	1.96 (1.57) ^c	1.14 (1.28) ^b	0.45 (0.97) ^b	0.24 (0.86) ^b	1.57	78.76		
6	Chlorantraniliprole 18.5% SC	100	30 (Drone)	4.95 (2.33)	1.98 (1.57) ^g	1.56 (1.44) ^g	0.85 (1.16) ^g	0.63 (1.06) ^g	4.58 (2.25)	2.25 (1.66) ^f	1.56 (1.44) ^f	0.64 (1.07) ^f	0.44 (0.97) ^f	1.81	75.50		
7	Chlorantraniliprole 18.5% SC (standard check)	200	500 (Knapsack)	4.86 (2.32)	2.76 (1.81) ^j	2.27 (1.66) ^j	1.35 (1.36) ^j	1.04 (1.24) ^j	4.45 (2.22)	2.67 (1.78) ^j	1.08 (1.26) ^{ab}	0.36 (0.93) ^{ab}	0.24 (0.86) ^b	2.11	71.43		
8	Spinetoram 11.7% SC	250	20 (Drone)	4.73 (2.29)	1.94 (1.56) ^d	1.35 (1.36) ^d	0.65 (1.07) ^d	0.42 (0.96) ^d	4.57 (2.25)	2.04 (1.59) ^d	1.25 (1.32) ^c	0.56 (1.03) ^c	0.34 (0.91) ^c	1.69	77.12		
9	Spinetoram 11.7% SC	187.5	20 (Drone)	4.92 (2.33)	2.05 (1.60) ^g	1.67 (1.47) ^g	0.95 (1.20) ^g	0.74 (1.11) ^g	4.66 (2.27)	2.23 (1.65) ^e	1.57 (1.44) ^f	0.75 (1.12) ^b	0.45 (0.97) ^f	1.90	74.27		
10	Spinetoram 11.7% SC	125	20 (Drone)	4.88 (2.32)	2.24 (1.65) ^j	1.86 (1.54) ^j	1.16 (1.29) ^j	0.93 (1.20) ^j	4.78 (2.30)	2.57 (1.75) ^j	1.85 (1.53) ^j	0.96 (1.21) ^j	0.64 (1.07) ^j	2.20	70.21		
11	Spinetoram 11.7% SC	250	30 (Drone)	4.75 (2.29)	1.76 (1.50) ^b	1.14 (1.28) ^b	0.45 (0.97) ^b	0.24 (0.86) ^b	4.44 (2.22)	1.85 (1.53) ^b	1.16 (1.29) ^b	0.44 (0.97) ^b	0.24 (0.86) ^b	1.55	79.01		
12	Spinetoram 11.7% SC	187.5	30 (Drone)	4.85 (2.31)	1.97 (1.57) ^j	1.46 (1.40) ^j	0.73 (1.11) ^j	0.52 (1.01) ^j	4.55 (2.25)	2.13 (1.62) ^e	1.35 (1.36) ^d	0.64 (1.07) ^j	0.35 (0.92) ^c	1.76	76.18		
13	Spinetoram 11.7% SC	125	30 (Drone)	4.94 (2.33)	2.15 (1.63) ^j	1.75 (1.50) ^j	1.06 (1.25) ^j	0.84 (1.16) ^j	4.68 (2.28)	2.45 (1.72) ^b	1.74 (1.50) ^b	0.84 (1.16) ^b	0.55 (1.02) ^b	2.10	71.57		

Table 1 continued...

Table 1 continued...

14	Spinetoram 11.7% SC (standard check)	250	500 (Knapsack)	4.87 (2.32)	2.84 (1.83) [*]	2.34 (1.68) [*]	1.46 (1.40) [*]	1.13 (1.28) [*]	4.54 (2.25)	2.76 (1.81) [*]	1.25 (1.32) [†]	0.56 (1.03) [†]	0.34 (0.91) [†]	2.21	70.08
15	Untreated	—	—	4.74 (2.29)	5.46 (2.44) [†]	7.87 (2.89) [†]	10.86 (3.37) [†]	12.64 (3.63) [†]	4.47 (2.23)	3.65 (2.04) [†]	5.17 (2.38) [†]	8.55 (3.01) [†]	10.44 (3.31) [†]	7.39	0.00
	S.E.m. ±			0.09	0.12	0.14	0.18	0.20	0.08	0.11	0.13	0.17	0.19		
	CD (P=0.05)			NS	0.35	0.41	0.53	0.58	NS	0.32	0.38	0.50	0.55		
	CV (%)			8.12	8.86	9.64	10.72	11.58	7.84	8.54	9.28	10.26	11.14		

Figures in parentheses are square root transformed values, NS- Non significant; The values denoted by a common letter are showing significant difference from each other as per DMRT; DBS= day before first spray, DAS= days after spray

density, canopy penetration and spray coverage, enabling greater deposition of insecticide droplets within the maize whorl where fall armyworm larvae remain concealed during feeding. In addition, the rotor-induced downwash generated by UAVs facilitates penetration of spray droplets into the crop canopy, thereby improving insecticide deposition on target sites. Similar findings were reported by Shan *et al.* (2022), who demonstrated that optimization of UAV spray volume significantly improved droplet deposition and biological efficacy against fall armyworm in maize. Liu *et al.* (2025) also reported that optimization of UAV operational parameters, particularly spray volume and flight characteristics, substantially enhanced insecticide deposition and control efficiency against *Spodoptera frugiperda*.

Among the insecticides evaluated, chlorantraniliprole consistently exhibited greater efficacy than spinetoram at corresponding dosages and spray volumes. The superior performance of chlorantraniliprole can be attributed to its anthranilic diamide mode of action, which activates insect ryanodine receptors, resulting in rapid cessation of feeding, muscular paralysis and mortality of lepidopteran larvae (Lahm *et al.*, 2005; Cordova *et al.*, 2006). Its excellent translaminar movement and prolonged residual activity further contribute to sustained suppression of larvae concealed within the maize whorl. Similar observations were reported by Deshmukh *et al.* (2020), who identified chlorantraniliprole as one of the most effective insecticides for field management of fall armyworm in maize. Prasanna *et al.* (2022) also recommended chlorantraniliprole as an effective component of integrated fall armyworm management programmes in maize owing to its rapid action and extended residual activity.

Although, spinetoram effectively reduced fall armyworm infestation, its efficacy was comparatively lower than chlorantraniliprole, particularly at reduced dosages. Spinetoram acts by activating nicotinic acetylcholine receptors and affecting α -aminobutyric acid (GABA)-gated chloride channels, leading to rapid paralysis and mortality of susceptible larvae (Sparks *et al.*, 2008). However, its field performance is strongly influenced by spray coverage and droplet deposition, emphasizing the importance of optimizing UAV operational parameters.

The superior performance of UAV-assisted spraying over conventional knapsack application observed in the present investigation corroborates the findings of Chen *et al.* (2021), who reported that UAV spraying significantly improves spray uniformity, canopy

penetration and pesticide use efficiency while reducing labour requirement and water consumption. Similar observations were made by Shanmugam *et al.* (2024), who demonstrated that UAV-assisted insecticide application significantly reduced fall armyworm infestation and improved operational efficiency compared with conventional ground-based spraying.

Bio-efficacy of recommended insecticides against stem borer, *Chilo partellus* during Kharif 2025–26

The efficacy of recommended insecticides applied through an unmanned aerial vehicle (UAV) at different spray volumes against maize stem borer, *Chilo partellus*, was evaluated by recording the number of leaves exhibiting characteristic pin-hole damage following two sequential insecticide applications. The results are presented in Table 2. The pre-treatment observations recorded one day before the first and second sprays (1 DBS) did not differ significantly among the treatments, indicating a uniform distribution of stem borer infestation before insecticide application.

Following the first spray, significant differences among treatments were observed from one day after spraying (1 DAS) onwards. Among all the treatments, chlorantraniliprole 18.5% SC applied at 200 ml ha⁻¹ through UAV with a spray volume of 30 L ha⁻¹ (T₄) recorded the lowest pin-hole damage throughout the observation period, with 1.28, 0.82, 0.26 and 0.12 damaged leaves plant⁻¹ at 1, 3, 7 and 10 DAS, respectively. This treatment was statistically superior to all other treatments and was closely followed by spinetoram 11.7% SC applied at 250 ml ha⁻¹ through UAV with 30 L ha⁻¹ spray volume (T₁₁), which recorded 1.36, 0.94, 0.34 and 0.14 damaged leaves plant⁻¹ during the corresponding observation periods. Chlorantraniliprole applied at 200 ml ha⁻¹ through UAV with 20 L ha⁻¹ spray volume (T₁) also provided excellent suppression of stem borer damage throughout the observation period.

A similar trend was observed following the second spray. Chlorantraniliprole 18.5% SC applied at 200 ml ha⁻¹ through UAV with 30 L ha⁻¹ spray volume (T₄) continued to record the lowest stem borer infestation, with only 1.08, 0.63, 0.18 and 0.09 damaged leaves plant⁻¹ at 1, 3, 7 and 10 DAS, respectively. This was closely followed by spinetoram 11.7% SC applied at 250 ml ha⁻¹ through UAV with 30 L ha⁻¹ spray volume (T₁₁), which recorded 1.14, 0.74, 0.21 and 0.10 damaged leaves plant⁻¹. The reduction in pin-hole damage after the second spray was greater than that observed after the first spray across all insecticide treatments, indicating cumulative suppression of the stem borer population following

sequential applications.

The pooled mean values further confirmed the superiority of chlorantraniliprole applied through UAV at higher spray volume. Chlorantraniliprole 18.5% SC applied at 200 ml ha⁻¹ with 30 L ha⁻¹ spray volume (T₄) recorded the lowest pooled mean pin-hole damage (0.98 damaged leaves plant⁻¹) with the highest reduction over control (87.04%). The next best treatment was spinetoram 11.7% SC applied at 250 ml ha⁻¹ through UAV with 30 L ha⁻¹ spray volume (T₁₁), which recorded a pooled mean of 1.03 damaged leaves plant⁻¹ and 86.38 per cent reduction over control. Chlorantraniliprole applied at 200 ml ha⁻¹ with 20 L ha⁻¹ spray volume (T₁) also performed well by recording a pooled mean of 1.06 damaged leaves plant⁻¹ with 85.98 per cent reduction over control. Among the intermediate dose treatments, chlorantraniliprole at 150 ml ha⁻¹ with 30 L ha⁻¹ spray volume (T₅) and spinetoram at 250 ml ha⁻¹ with 20 L ha⁻¹ spray volume (T₈) recorded pooled means of 1.12 and 1.13 damaged leaves plant⁻¹, respectively.

Lower insecticide dosages resulted in comparatively higher stem borer damage irrespective of spray volume. Chlorantraniliprole applied at 100 ml ha⁻¹ through UAV with 30 L ha⁻¹ spray volume (T₆) recorded a pooled mean of 1.35 damaged leaves plant⁻¹ with 82.14 per cent reduction over control, whereas the corresponding treatment with 20 L ha⁻¹ spray volume (T₃) recorded a pooled mean of 1.46 damaged leaves plant⁻¹ and 80.69 per cent reduction over control. Similarly, spinetoram applied at 125 ml ha⁻¹ through UAV with 30 L ha⁻¹ spray volume (T₁₃) recorded a pooled mean of 1.47 damaged leaves plant⁻¹, while the corresponding 20 L ha⁻¹ treatment (T₁₀) recorded 1.61 damaged leaves plant⁻¹.

The conventional knapsack applications were comparatively less effective than the corresponding UAV applications. Chlorantraniliprole applied through a knapsack sprayer (T₇) recorded a pooled mean of 1.92 damaged leaves plant⁻¹ with 74.60 per cent reduction over control, whereas spinetoram applied through a knapsack sprayer (T₁₄) recorded a pooled mean of 1.97 damaged leaves plant⁻¹ with 73.94 per cent reduction over control. The untreated control exhibited a continuous increase in stem borer infestation after both sprays, reaching 12.18 and 12.66 damaged leaves plant⁻¹ at 10 DAS following the first and second sprays, respectively.

The present study clearly demonstrated that UAV application with a spray volume of 30 L ha⁻¹ consistently provided superior suppression of stem borer compared with 20 L ha⁻¹ spray volume and conventional knapsack application. The improved performance at the higher

Table 2 : Bio-efficacy of recommended insecticides against stem borer, *Chilo partellus* in maize during *Kharif* 2025-26.

S. no.	Treatment details	Dose (ml/ha)	Spray equipment	No. of leaves with pin holes/ plant												%ROC	
				First Spray						Second Spray							Mean
				1 DBS	1 DAS	3 DAS	7 DAS	10 DAS	1 DBS	1 DAS	3 DAS	7 DAS	10 DAS				
1	Chlorantraniliprole 18.5% SC	200	20 (Drone)	2.84 (1.83)	1.42 (1.39) ^{bc}	0.96 (1.21) ^{bc}	0.34 (0.92) ^{bc}	0.16 (0.81) ^{bc}	2.63 (1.77)	1.16 (1.29) ^b	0.72 (1.11) ^b	0.22 (0.85) ^b	0.11 (0.78) ^b	1.06	85.98		
2	Chlorantraniliprole 18.5% SC	150	20 (Drone)	2.92 (1.85)	1.58 (1.44) ^{de}	1.14 (1.28) ^{de}	0.56 (1.03) ^{de}	0.34 (0.92) ^{de}	2.74 (1.80)	1.34 (1.35) ^d	0.94 (1.20) ^d	0.38 (0.94) ^d	0.22 (0.85) ^d	1.22	83.86		
3	Chlorantraniliprole 18.5% SC	100	20 (Drone)	2.97 (1.86)	1.86 (1.54) ^{hi}	1.47 (1.40) ^{hi}	0.83 (1.15) ^{hi}	0.64 (1.07) ^{hi}	2.82 (1.82)	1.62 (1.46) ^h	1.26 (1.33) ^h	0.66 (1.08) ^h	0.46 (0.98) ^h	1.46	80.69		
4	Chlorantraniliprole 18.5% SC	200	30 (Drone)	2.76 (1.81)	1.28 (1.33) ^a	0.82 (1.15) ^a	0.26 (0.87) ^a	0.12 (0.79) ^a	2.57 (1.75)	1.08 (1.26) ^a	0.63 (1.06) ^a	0.18 (0.82) ^a	0.09 (0.77) ^a	0.98	87.04		
5	Chlorantraniliprole 18.5% SC	150	30 (Drone)	2.85 (1.83)	1.47 (1.40) ^{cd}	1.03 (1.24) ^{cd}	0.43 (0.96) ^{cd}	0.24 (0.86) ^{cd}	2.66 (1.78)	1.22 (1.31) ^c	0.84 (1.16) ^c	0.31 (0.90) ^c	0.16 (0.81) ^c	1.12	85.19		
6	Chlorantraniliprole 18.5% SC	100	30 (Drone)	2.93 (1.85)	1.74 (1.50) ^{fg}	1.36 (1.36) ^{fg}	0.72 (1.10) ^{fg}	0.52 (1.01) ^{fg}	2.74 (1.80)	1.481.14 (1.41) ^f	0.54 (1.28) ^f	0.34 (1.02) ^f	1.35 (0.91) ^f	82.14			
7	Chlorantraniliprole 18.5% SC (standard check)	200	500 (Knapsack)	2.88 (1.84)	2.64 (1.77) ^{jk}	2.16 (1.63) ^{jk}	1.36 (1.36) ^{jk}	1.08 (1.26) ^{jk}	2.69 (1.79)	2.36 (1.69) ^j	1.92 (1.56) ^j	1.18 (1.30) ^j	0.92 (1.19) ^j	1.92	74.60		
8	Spinetoram 11.7% SC	250	20 (Drone)	2.83 (1.82)	1.46 (1.40) ^{cd}	1.06 (1.25) ^{cd}	0.46 (0.98) ^{cd}	0.23 (0.85) ^{cd}	2.65 (1.77)	1.24 (1.32) ^c	0.86 (1.17) ^c	0.32 (0.91) ^c	0.18 (0.82) ^c	1.13	85.05		
9	Spinetoram 11.7% SC	187.5	20 (Drone)	2.95 (1.86)	1.82 (1.52) ^{gh}	1.43 (1.39) ^{gh}	0.76 (1.12) ^{gh}	0.54 (1.02) ^{gh}	2.76 (1.81)	1.52 (1.42) ^g	1.18 (1.30) ^g	0.58 (1.04) ^g	0.38 (0.94) ^g	1.39	81.61		
10	Spinetoram 11.7% SC	125	20 (Drone)	3.04 (1.88)	1.98 (1.57) ^{ij}	1.72 (1.49) ^{ij}	1.06 (1.25) ^{ij}	0.84 (1.16) ^{ij}	2.84 (1.83)	1.78 (1.51) ⁱ	1.46 (1.40) ⁱ	0.82 (1.15) ⁱ	0.58 (1.04) ⁱ	1.61	78.70		
11	Spinetoram 11.7% SC	250	30 (Drone)	2.78 (1.81)	1.36 (1.36) ^{ab}	0.94 (1.20) ^{ab}	0.34 (0.92) ^{ab}	0.14 (0.80) ^{ab}	2.59 (1.76)	1.14 (1.28) ^{ab}	0.74 (1.11) ^a	0.21 (0.84) ^a	0.10 (0.77) ^a	1.03	86.38		
12	Spinetoram 11.7% SC	187.5	30 (Drone)	2.86 (1.83)	1.64 (1.46) ^{ef}	1.18 (1.30) ^{ef}	0.64 (1.07) ^{ef}	0.42 (0.96) ^{ef}	2.68 (1.78)	1.36 (1.36) ^e	0.98 (1.22) ^e	0.42 (0.96) ^e	0.24 (0.86) ^e	1.24	83.60		
13	Spinetoram 11.7% SC	125	30 (Drone)	2.94 (1.85)	1.92 (1.56) ^{hi}	1.54 (1.43) ^{hi}	0.84 (1.16) ^{hi}	0.63 (1.06) ^{hi}	2.76 (1.81)	1.64 (1.46) ^b	1.28 (1.33) ^b	0.68 (1.09) ^b	0.48 (0.99) ^b	1.47	80.56		

Table 2 continued...

Table 2 continued...

14	Spinetoram 11.7% SC (standard check)	250	500 (Knapsack)	2.89 (1.84)	2.72 (1.79) ^k	2.24 (1.66) ^k	1.42 (1.39) ^k	1.14 (1.28) ^k	2.72 (1.79)	2.42 (1.71) ^k	1.98 (1.57) ^k	1.24 (1.32) ^k	0.96 (1.21) ^k	1.97	73.94
15	Untreated	—	—	2.96 (1.86)	4.86 (2.32) ^j	6.74 (2.69) ^j	10.34 (3.29) ^j	12.18 (3.56) ^j	2.81 (1.82)	5.18 (2.38) ^j	7.08 (2.75) ^j	10.82 (3.36) ^j	12.66 (3.63) ^j	7.56	0.00
	S.Em. ±			0.08	0.10	0.12	0.16	0.18	0.07	0.09	0.11	0.15	0.17		
	CD (P=0.05)			NS	0.30	0.35	0.47	0.52	NS	0.27	0.33	0.44	0.49		
	CV (%)			7.68	8.34	9.02	10.08	10.92	7.32	8.06	8.78	9.86	10.74		

Figures in parentheses are square root transformed values, NS- Non significant; The values denoted by a common letter are showing significant difference from each other as per DMRT; DBS= day before first spray; DAS= days after spray.

spray volume can be attributed to greater droplet density, better canopy penetration and more uniform spray distribution within the maize whorl, enabling enhanced insecticide deposition on feeding sites of newly hatched larvae before they tunnel into the stem. Rotor-generated downwash produced by UAVs further facilitates droplet movement into concealed portions of the crop canopy, thereby improving biological efficacy. Similar findings were reported by Shan *et al.* (2022), who observed that optimization of UAV spray volume significantly enhanced droplet deposition and control efficiency against lepidopteran pests in maize. Likewise, Liu *et al.* (2025) demonstrated that appropriate optimization of UAV operational parameters improved spray coverage, canopy penetration and insecticide deposition, resulting in enhanced control of *Spodoptera frugiperda* and other maize pests.

Among the insecticides evaluated, chlorantraniliprole consistently outperformed spinetoram at corresponding spray volumes and dosages. The superior efficacy of chlorantraniliprole may be attributed to its anthranilic diamide chemistry, which activates insect ryanodine receptors, causing rapid feeding cessation, muscle paralysis and mortality of lepidopteran larvae (Cordova *et al.*, 2006). In addition, its excellent translaminar movement and prolonged residual activity provide sustained protection by controlling larvae before stem penetration. Similar superiority of chlorantraniliprole against maize stem borer and other lepidopteran pests has been reported by Deshmukh *et al.* (2020) and Prasanna *et al.* (2022), who identified chlorantraniliprole as one of the most effective insecticides for integrated management of maize insect pests.

Although, spinetoram also provided effective suppression of stem borer, its efficacy remained marginally lower than chlorantraniliprole, particularly at reduced dosages. Spinetoram acts primarily by activating nicotinic acetylcholine receptors and disrupting γ -aminobutyric acid (GABA)-gated chloride channels, leading to rapid paralysis of susceptible larvae (Sparks *et al.*, 2008). However, adequate spray coverage and optimum droplet deposition are essential to maximize its field performance under UAV application.

The superiority of UAV-assisted spraying over conventional knapsack application observed in the present investigation corroborates the findings of Chen *et al.* (2021), who reported that UAV spraying enhances spray uniformity, canopy penetration and pesticide use efficiency while substantially reducing labour requirement and water consumption. Similar observations were made by

Table 3 : Cost economics of drone application in the management of maize pests during *Kharif* 2025-26.

S. no.	Treatment Details	Dose (ml/ha)	Spray Equipment	Yield (q/ha)	Total Cost of cultivation (₹/ha)	Gross Returns (₹/ha)	Net Returns (₹/ha)	B:C Ratio
1	Chlorantraniliprole 18.5 SC	200	Drone (20 L/ha)	37.2 ^{ab}	59,500	111,600	52,100	1.87
2	Chlorantraniliprole 18.5 SC	150	Drone (20 L/ha)	35.8 ^{bc}	58,700	107,400	48,700	1.83
3	Chlorantraniliprole 18.5 SC	100	Drone (20 L/ha)	34.2 ^{de}	57,900	102,600	44,700	1.77
4	Chlorantraniliprole 18.5 SC	200	Drone (30 L/ha)	38.8 ^a	59,800	116,400	56,600	1.95
5	Chlorantraniliprole 18.5 SC	150	Drone (30 L/ha)	37.1 ^{ab}	59,000	111,300	52,300	1.89
6	Chlorantraniliprole 18.5 SC	100	Drone (30 L/ha)	35.5 ^{bc}	58,200	106,500	48,300	1.83
7	Chlorantraniliprole 18.5 SC	200	Knapsack (500 L/ha)	35.0 ^{cd}	60,500	105,000	44,500	1.74
8	Spinetoram 11.7 SC	250	Drone (20 L/ha)	34.8 ^{cd}	60,200	104,400	44,200	1.73
9	Spinetoram 11.7 SC	187.5	Drone (20 L/ha)	33.4 ^{cd}	59,400	100,200	40,800	1.69
10	Spinetoram 11.7 SC	125	Drone (20 L/ha)	31.8 ^b	58,600	95,400	36,800	1.63
11	Spinetoram 11.7 SC	250	Drone (30 L/ha)	36.0 ^{bc}	60,500	108,000	47,500	1.79
12	Spinetoram 11.7 SC	187.5	Drone (30 L/ha)	34.7 ^{cd}	59,700	104,100	44,400	1.74
13	Spinetoram 11.7 SC	125	Drone (30 L/ha)	33.1 ^{ef}	58,900	99,300	40,400	1.69
14	Spinetoram 11.7 SC	250	Knapsack (500 L/ha)	32.8 ^{fg}	61,000	98,400	37,400	1.61
15	Untreated Control	—	—	24.8 ^h	56,500	74,400	17,900	1.32
S.E.m. ±				1.74	—	—	—	—
CD (P=0.05)				4.86	—	—	—	—
CV (%)				10.68	—	—	—	—

Shanmugam *et al.* (2024), who demonstrated that UAV-assisted insecticide application significantly reduced maize pest infestation and improved operational efficiency compared with conventional ground-based spraying.

Cost economics of drone application in the management of maize pests during *Kharif* 2025–26

The economics of different insecticide treatments applied through an unmanned aerial vehicle (UAV) and conventional knapsack sprayer against major insect pests of maize were evaluated based on grain yield, total cost of cultivation, gross returns, net returns and benefit:cost ratio. The results are presented in Table 3. Significant differences in grain yield were observed among the treatments, indicating that effective pest management through optimized UAV application had a direct influence on crop productivity and economic returns.

Among all the treatments, chlorantraniliprole 18.5% SC applied at 200 ml ha⁻¹ through UAV with a spray volume of 30 L ha⁻¹ (T₄) recorded the highest grain yield (38.8 q ha⁻¹), which was significantly superior to all other treatments. This treatment also realized the highest gross returns (₹ 1,16,400 ha⁻¹), net returns (₹ 56,600 ha⁻¹) and

benefit:cost ratio (1.95), indicating its superior economic viability. The higher profitability of this treatment can be attributed to its excellent efficacy against both fall armyworm and stem borer, resulting in reduced crop damage and improved grain yield.

Among the remaining chlorantraniliprole treatments, application of chlorantraniliprole 18.5% SC at 200 ml ha⁻¹ through UAV with 20 L ha⁻¹ spray volume (T₁) recorded a grain yield of 37.2 q ha⁻¹, gross returns of ₹ 1,11,600 ha⁻¹, net returns of ₹ 52,100 ha⁻¹ and a benefit:cost ratio of 1.87. Chlorantraniliprole applied at 150 ml ha⁻¹ with 30 L ha⁻¹ spray volume (T₅) recorded a grain yield of 37.1 q ha⁻¹, gross returns of ₹ 1,11,300 ha⁻¹, net returns of ₹ 52,300 ha⁻¹ and a benefit:cost ratio of 1.89. The corresponding treatment with 20 L ha⁻¹ spray volume (T₂) recorded a comparatively lower grain yield of 35.8 q ha⁻¹ and a benefit:cost ratio of 1.83. Likewise, chlorantraniliprole applied at 100 ml ha⁻¹ through UAV with 30 L ha⁻¹ spray volume (T₆) recorded a grain yield of 35.5 q ha⁻¹, which was slightly higher than the corresponding treatment with 20 L ha⁻¹ spray volume (T₃), which produced 34.2 q ha⁻¹. The conventional knapsack application of chlorantraniliprole (T₇) recorded

a grain yield of 35.0 q ha⁻¹ with gross returns of ` 1,05,000 ha<sup>-1</sup>, net returns of ` 44,500 ha⁻¹ and a benefit:cost ratio of 1.74.

A similar trend was observed among the spinetoram treatments. Spinetoram 11.7% SC applied at 250 ml ha⁻¹ through UAV with a spray volume of 30 L ha⁻¹ (T₁₁) recorded the highest grain yield (36.0 q ha⁻¹) among the spinetoram treatments, along with gross returns of ` 1,08,000 ha<sup>-1</sup>, net returns of ` 47,500 ha⁻¹ and a benefit:cost ratio of 1.79. The corresponding treatment with 20 L ha⁻¹ spray volume (T₈) recorded a grain yield of 34.8 q ha⁻¹ with a benefit:cost ratio of 1.73. Reduction in insecticide dosage resulted in comparatively lower grain yield and profitability. Spinetoram applied at 187.5 ml ha⁻¹ through UAV with 30 L ha⁻¹ spray volume (T₁₂) recorded a grain yield of 34.7 q ha⁻¹, whereas the corresponding treatment with 20 L ha⁻¹ spray volume (T₉) recorded 33.4 q ha⁻¹. Similarly, spinetoram applied at 125 ml ha⁻¹ through UAV with 30 L ha⁻¹ spray volume (T₁₃) recorded a grain yield of 33.1 q ha⁻¹, which was marginally higher than the corresponding 20 L ha⁻¹ treatment (T₁₀), which recorded 31.8 q ha⁻¹. The conventional knapsack application of spinetoram (T₁₄) recorded a grain yield of 32.8 q ha⁻¹ with gross returns of ` 98,400 ha<sup>-1</sup>, net returns of ` 37,400 ha⁻¹ and a benefit:cost ratio of 1.61.

The untreated control recorded the lowest grain yield (24.8 q ha⁻¹), gross returns (` 74,400 ha<sup>-1</sup>), net returns (` 17,900 ha⁻¹) and benefit:cost ratio (1.32), clearly demonstrating the substantial yield and economic losses caused by uncontrolled infestation of fall armyworm and stem borer.

The superior economic performance of UAV application with a spray volume of 30 L ha⁻¹ observed in the present investigation can be attributed to improved spray deposition, enhanced canopy penetration and more uniform distribution of insecticide droplets throughout the maize canopy, which resulted in superior management of both target pests. Effective suppression of pest infestation during critical crop growth stages minimized feeding damage, protected photosynthetic leaf area and ultimately enhanced grain yield. Moreover, UAV application considerably reduced labour requirements, minimized water consumption and enabled rapid and timely insecticide application over large areas, thereby improving operational efficiency. Similar findings were reported by Chen *et al.* (2021), who concluded that UAV-assisted pesticide application improves spray deposition, enhances pesticide use efficiency and reduces labour and water requirements while increasing crop productivity. Among the insecticides evaluated, chlorantraniliprole

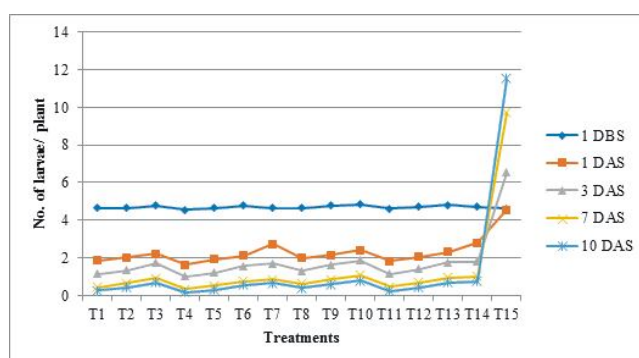


Fig. 1 : Bio-efficacy of recommended insecticides against fall armyworm, *Spodoptera frugiperda* in maize during Kharif 2025-26.

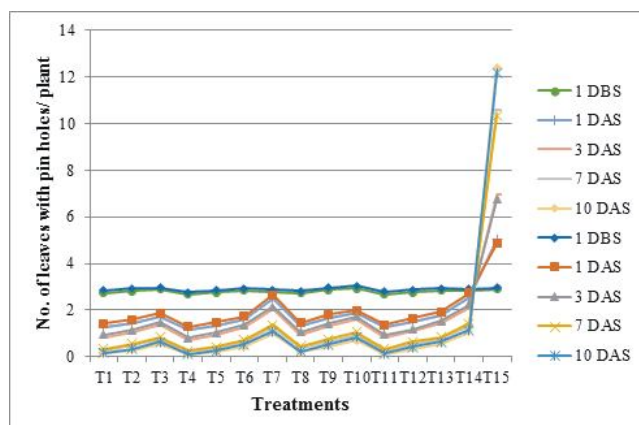


Fig. 2 : Bio-efficacy of recommended insecticides against stem borer, *Chilo partellus* in maize during Kharif 2025-26.

consistently generated higher economic returns than spinetoram at corresponding spray volumes and dosages. This may be attributed to its superior efficacy, prolonged residual activity and rapid suppression of lepidopteran pests, which provided sustained crop protection and greater yield realization. Comparable findings were reported by Deshmukh *et al.* (2020), who observed significantly higher maize yields and economic returns following effective management of fall armyworm with chlorantraniliprole under field conditions. Similarly, Prasanna *et al.* (2022) reported that effective management of maize insect pests through timely application of chlorantraniliprole substantially reduced yield losses and improved profitability.

The better economic performance of UAV application compared with conventional knapsack spraying also corroborates the findings of Shan *et al.* (2022), who reported that optimization of UAV operational parameters significantly improved biological efficacy and economic returns by increasing spray deposition and reducing operational costs. Likewise, Shanmugam *et al.* (2024) demonstrated that UAV-assisted pesticide application provided higher profitability than conventional ground

spraying owing to improved field efficiency, reduced labour costs and enhanced pest control efficiency.

Overall, the present investigation demonstrated that chlorantraniliprole 18.5% SC applied at 200 ml ha⁻¹ through UAV with a spray volume of 30 L ha⁻¹ was the most economically viable treatment for the management of major insect pests of maize during Kharif 2025–26. The study further established that optimization of UAV spray volume, together with the use of an effective insecticide, substantially improved grain yield, net returns and benefit:cost ratio, thereby providing a profitable and sustainable operational protocol for precision pest management in maize.

Conclusion

The present investigation demonstrated that optimization of spray volume and insecticide dosage substantially improved the efficiency of UAV-assisted insecticide application against major insect pests of maize. Chlorantraniliprole 18.5% SC applied at 200 ml ha⁻¹ through an unmanned aerial vehicle with a spray volume of 30 L ha⁻¹ proved to be the most effective treatment by recording the lowest fall armyworm population, minimum stem borer damage, highest grain yield, maximum net returns and the highest benefit:cost ratio. The higher efficacy of this treatment was primarily attributed to improved spray deposition, greater canopy penetration and superior coverage achieved under the optimized UAV operational protocol. Compared with conventional knapsack spraying, UAV application required substantially less spray volume, reduced labour input and enhanced operational efficiency without compromising biological efficacy. The findings of the present study establish that UAV-assisted application of chlorantraniliprole at the optimized spray volume of 30 L ha⁻¹ can be recommended as a technically efficient, economically viable and environmentally sustainable approach for precision management of fall armyworm and stem borer in maize under field conditions.

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