Indian Journal of Ecology (2025) 52(6) (SI): 1898-1903
DOI: https://doi.org/10.55362/IJE/2025/4751

Manuscript Number: 4751
NAAS Rating: 5.38

Drone-Based Application of Pesticide Combinations for the Management of Fall Armyworm and Banded Leaf and Sheath Blight in Maize

P. Reshma, Rajasri Mandali, J. Manjunath, M.K. Jyosthna and P. Maheswara Reddy
Acharya N. G. Ranga Agricultural University, Lam, Guntur- 522 034, India
E-mail: m.rajasri@angrau.ac.in

***Abstract*:** The simultaneous occurrence of invasive fall armyworm (*Spodoptera frugiperda*) and banded leaf and sheath blight (BLSB, *Rhizoctonia solani*) poses significant threat to maize productivity. The study was conducted at wet land farm, S. V. Agricultural College, Tirupati, (latitude 13.615395°N and longitude 79.373317°E) during *Rabi*, 2023-24, to evaluate the efficacy of drone-based application of a combination of chlorantraniliprole 18.5 % SC and azoxystrobin 18.2 % + difenoconazole11.4 % SC against these pests. The results demonstrated that drone spraying of the insecticide-fungicide combination was highly effective in controlling FAW, achieving over 80 % reduction in larval population and 52% reduction in leaf damage. This approach also resulted in higher yields (46.8 q/ ha) with cost-benefit ratio of 1:2.24. In contrast, conventional knapsack spraying was less effective. The drone-based application minimized BLSB incidence, with negligible disease occurrence compared to untreated controls (1.13-2.13 %) with uniform distribution, improved penetration and reduced drift. The study establishes the efficiency and feasibility of UAV-based pesticide delivery for integrated pest and disease management in maize.

***Keywords*:** Drone application, Maize, *Rhizoctonia solani, Spodoptera frugiperda*, UAV

Maize (*Zea mays* L.), is India's third most important crop after rice and wheat, providing food, feed, fodder, and industrial raw material. India ranks sixth globally in maize production (32.47 million tonnes from 9.96 million ha; 3260 kg/ha), with Andhra Pradesh leading in productivity (6066 kg/ha). However, pests and diseases such as the fall armyworm (FAW) (*Spodoptera frugiperda*), a migratory pest first reported in Africa (Goergen et al., 2016) and later in India at Shivamogga, Karnataka (Sharanabasappa et al., 2018), caused 21-53 % yield loss (Abrahams et al., 2017). Likewise, banded leaf and sheath blight (BLSB) (*Rhizoctonia solani*) leads to 11-40 % yield reduction, reaching 100 % under favourable conditions (Sharma and Saxena 2002). The simultaneous occurrence of FAW and BLSB in maize poses a serious threat to farmers, causing heavy yield losses. To manage both pests and diseases, farmers often mix pesticides in a single tank for broader control and reduced costs. However, such combinations require evaluation for bioefficacy and compatibility, as interactions may be antagonistic, additive, or synergistic (Gandini et al., 2020). Physical incompatibility between insecticide–fungicide mixtures can cause sedimentation, nozzle clogging, and uneven spray. Unmanned Aerial Vehicles (UAVs) have emerged as efficient tools in precision agriculture, offering uniform spraying, high maneuverability, and rapid field coverage. Operating at low altitudes minimizes drift compared to manned aerial spraying (Huang et al., 2009, Li et al., 2021). The rotor-induced vertical airflow improves droplet atomization, penetration, and deposition on crop surfaces and whorls, ensuring effective pesticide delivery.

Recently introduced new insecticide and fungicide combinations have been adopted by the maize farmers for managing pests and diseases, but the research studies on their compatibility and phytotoxicity effects in maize are very scanty. Therefore, evaluating their compatibility, bio-efficacy and the potential of drone-based application is essential to enhance efficiency, save time and labour. Hence, present study was undertaken to evaluate the compatibility, phytotoxicity and field efficacy of drone-based application of chlorantraniliprole and azoxystrobin + difenoconazole mixtures for the simultaneous management of FAW and BLSB in maize.

MATERIAL AND METHODS

Physical compatibility: The physical compatibility of chlorantraniliprole 18.5 % SC and fungicide, azoxystrobin 18.2 % + difenoconazole 11.4 % SC) was assessed using jar compatibility test. Observations were recorded after 30 and 60 minutes for the development of incompatible phenomenon like flakes, precipitation, gel, slurry, foams, sedimentation.

Experimental design: The field experiment was conducted at wet land farm, S. V. Agricultural College, Tirupati, (latitude 13.615395 °N and longitude 79.373317 °E), Andhra Pradesh, India during *Rabi*, 2023- 24, with Ganga Kaveri hybrid maize in randomised block design with three treatments and six replications with the plot size of 50 m × 10 m with inter- row spacing of 60 cm and 20 cm intra- row spacing. Buffer zone with 50 m × 10 m distance was maintained between the treatments.

Drone specifications: The ANGRAU-Pushpak-03 drone (Officially designated Remotely Piloted Aircraft System approved by DGCA, equipped with four anti-drift flat fan nozzles) was operated as per the SOP developed by ANGRAU at a flying speed of 4.5 m/s and a height of 1.5 m above the crop canopy, with a spray swath of 4 m, spray width of 2.8 m and a payload capacity of 12 L.

Plant protection applications were imposed at seedling stage (15-25 DAP) and tasselling stage (47-50 DAP) of maize crop (Fig. 1). The commercial formulations of insecticide (chlorantraniliprole 18.5 % SC @ 0.5 ml/l) and fungicide (azoxystrobin 18.2% + difenoconazole 11.4 % SC @1 ml/L) were pre mixed in a known quantity of water in separate vessel. The spray volume used for knapsack sprayer and drone were 500 l/ ha and 25 l/ha respectively. Before each treatment, the pesticide tank was completely cleaned to eliminate any potential incompatibilities that could have been brought over by leftover spray fluid of insecticides. The solution was well mixed before being transferred to the drone's pesticide tank, where it was blended with the remaining water to make up the required spray volume. The wind speed and temperature were recorded with digital anemometer before spraying and confirmed to be below 3 m/s and 35°C. The drone spraying of pesticides (chlorantraniliprole18.5 % SC @ 0.5 ml/l + azoxystrobin 18.2 % + difenoconazole 11.4 % SC @ 1 ml/l) was compared with conventional sprayer. Phyto toxicity studies were conducted with the test pesticides both at the recommended dose and the double the recommended dose using Knapsack and Drone sprays and the symptoms such as chlorotic leaf margins and laminae, reddish or purplish veins, wrinkled leaves, stunted growth, necrosis (death of leaf tissue), wilting and whiplashing were recorded at 1, 3, 5 and 7 days after spray.

Fig. 1. UAV, ANGRAU- PUSHPAK- 03 drone spraying on maize

Distribution of droplets on water sensitive spray cards: After spraying, water sensitive papers were collected and placed in marked envelops one by one according to treatments. Distribution analysis was performed using the 'Drop leaf' mobile app developed by Brandoli et al. (2020) by uploading images of water-sensitive papers collected from the field after spraying. The data on number of drops, mean diameter of droplet (μm), coverage area per cent, density (drops cm^{-2}), Dv 0.1 (μm), Dv 0.5 (μm) and Dv 0.9 (μm) were analyzed and tabulated.

Statistical analysis: The data were subjected to suitable transformation and analyzed using SPSS statistical package version 20 and treatment means were compared using Duncan's Multiple Range Test (DMRT) at 5% significance (P=0.05).

RESULTS AND DISCUSSION

Compatibility and phytotoxicity: The insecticide –fungicide mixture showed physical compatibility with no sedimentation, foaming, or precipitation even after 60 minutes, indicating safe spray ability without nozzle clogging. Reshma et al. (2024) also reported compatibility between chlorantraniliprole and azoxystrobin + difenoconazole, and Visalakshmi et al. (2016) observed several insecticides (chlorantraniliprole, chlorpyriphos, cartap hydrochloride, flubendiamide, profenophos) compatible with trifloxystrobin + tebuconazole and propiconazole. Compatibility among various insecticides, fungicides, and 19:19:19 N:P:K fertilizer was also documented by Anil et al.,. (2024), while Sandhya et al. (2021) confirmed similar results for lambda-cyhalothrin + chlorantraniliprole, azadirachtin, and azoxystrobin + difenoconazole or carbendazim + mancozeb. Additional jar-test studies by Matcha (2021) and Ragiman et al. (2023) further support these findings.

Phytotoxicity evaluated at double the recommended dose on maize revealed no symptoms for chlorantraniliprole + azoxystrobin + difenoconazole under both sprayers. Kandpal and Srivastava (2023) also reported non-phytotoxic and compatible mixtures involving lambda-cyhalothrin + chlorantraniliprole, flubendiamide, azadirachtin, and azoxystrobin + difenoconazole. Similarly, Ogura et al. (2023) observed no phytotoxicity with fipronil and 2,4-D.

Droplet distribution: Data on mean droplet size, droplet density, coverage area, number of drops and mean diameter were obtained from water-sensitive spray cards using the Dropleaf app. Droplet size (VMD, Dv0.5) was higher under drone spraying (829.52, 721.25, 644.56 µm) than knapsack spraying (678.15, 560.69, 345.23 µm) at the upper, middle and lower maize canopy, respectively, indicating reduced drift due to larger droplets. Droplet density decreased down the canopy, but drone spraying recorded higher droplets/cm² 82.28 (upper), 44.99 (middle) and 24.76 (lower) compared to knapsack spraying (20.23, 15.56 and 7.14 droplets/cm²), with a smaller CV, reflecting better uniformity and canopy penetration.

For drone spraying, Dv0.1 and Dv0.9 were 216.64 and 647.19 µm (upper), 232.67 and 491.18 µm (middle), and 187.87 and 569.95 µm (lower). For knapsack spraying, they were higher at the upper layer (150.22 and 789.32 µm) compared to middle (123.54 and 879.32 µm) and bottom layers (145.68 and 879.66 µm). Coverage area was highest in the upper knapsack layer (98.55%), comparable with the upper drone layer (96.65%), followed by middle knapsack (96.56%) and lower drone layers (90.49% and 90.29%). Mean droplet diameter in drone spraying was 1156.77, 813.60 and 501.74 µm (upper, middle, lower), whereas in knapsack spraying it was 1726.56, 1581.30 and 779.87 µm (Table 1, Fig. 2). These results agree with earlier UAV studies. Chen et al. (2020) reported highest droplet deposition in upper cotton canopy layers. Zhang et al. (2022) recorded uniform droplet density of 54.61/cm² in sugarcane; and Dengeru et al. (2022) observed similar patterns in red gram.**Management of fall armyworm:** Drone spraying of pesticide combinations performed better than knapsack application. After the first spray, drone plots recorded 3.44 larvae/10 plants and 40.29% leaf damage, compared to 3.43 larvae and 43.34% in knapsack spraying. After the second spray, drone spraying again showed lower larval counts and leaf damage (0.75 larvae; 37.25%) than knapsack (0.92 larvae; 49.43%). Across 3, 5, 7 and 10 days after both sprays, the most effective treatment was drone spraying of chlorantraniliprole + azoxystrobin + difenoconazole, with the lowest mean larval count (2.10/10 plants), highest larval reduction over control (84.59%), lowest mean leaf damage (37.01%), highest reduction in leaf damage (52.84%) and

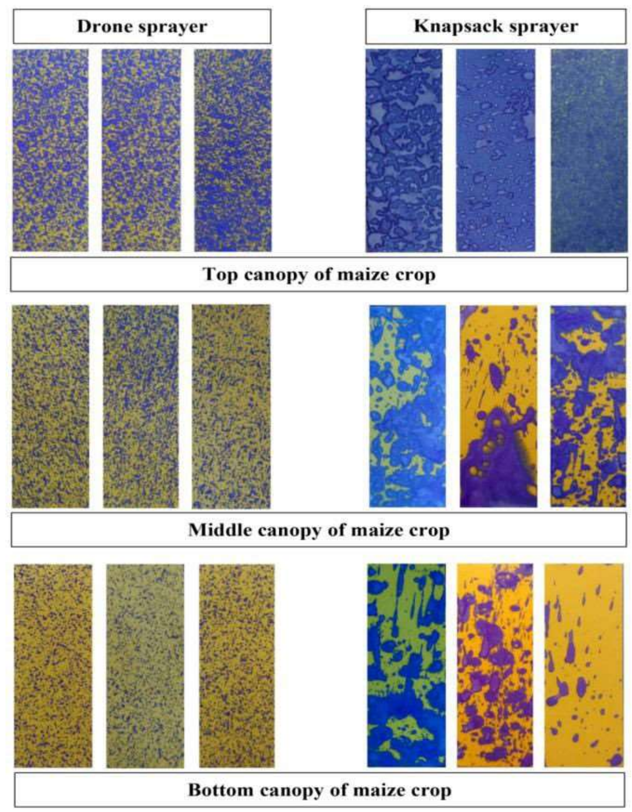

Fig. 2. Droplet deposition of pesticide on water spraying cards on top, middle and bottom canopy in maize

Table 1. Characteristics of droplet deposition, droplet density using drone spraying of pesticides on maize leaves

WSP position (Canopy of maize crop)	Droplet size			Droplet density (drops/ cm^2)	Coverage area (%)	Mean diameter (µm)
	Dv0.1 (µm)	Dv0.5 (VMD) (µm)	Dv0.9 (µm)			
Upper (Drone spray)	216.64	829.52	647.19	82.28 ^{a}	96.65 ^{a}	1156.77
Middle (Drone spray)	232.67	721.25	491.18	44.99 ^{b}	96.27 ^{a}	813.60
Bottom (Drone spray)	187.87	644.56	569.95	24.76 ^{c}	90.49 ^{b}	501.74
Upper (Knapsack spray)	150.22	678.15	789.32	20.23 ^{d}	98.55 ^{a}	1726.56
Middle (Knapsack spray)	123.54	560.69	879.54	15.65 ^{e}	96.56 ^{a}	1581.30
Bottom (Knapsack spray)	145.68	345.23	879.66	7.14 e	90.29 ^{b}	779.87

Values followed by the same letter in each column are not significantly different as per DMRT (P=0.05)
Dv0.5 - VMD (Volume Median Diameter) , Dv0.1 - 10 % droplets in volume spray which is smaller than VMD Dv0.9 - 90 % droplets in volume spray which is smaller than VMD

lowest Davis score (2.75). Knapsack spraying of the same combination was slightly inferior, recording 2.18 larvae (84.01% reduction), 39.59% leaf damage (48.39% reduction) and Davis score 2.75.

Management of BLSB: The incidence of BLSB was very much negligible in the treated maize plots (both drone spray and knapsack spray) with insecticide + fungicide combinations which were initiated at 20 days after sowing along with the incidence of FAW on maize. These prophylactic combination sprays might have reduced the BLSB incidence in treated plots whereas 1.13 to 2.13 % incidence of BLSB was recorded in the untreated control (Table 2).

Yield and economics: Drone applications of pesticide combinations resulted in higher yields than corresponding knapsack sprays. The highest yield was recorded with drone spraying of chlorantraniliprole + azoxystrobin + difenoconazole (46.86 q/ha), followed by the same combination applied with a knapsack sprayer (40.55 q/ha). Drone spraying also produced the highest additional yield over the untreated control (₹52,488/ha) compared to knapsack spraying (₹36,450/ha), with superior cost–benefit ratios of 1:2.41 and 1:1.89, respectively (Table 3). Overall, drone spraying of both insecticide + fungicide combinations outperformed knapsack application. These findings agree with earlier UAV studies. Sambaiah et al. (2022) reported better control of rice leaf folder using the "ANGRAU-Pushpak-01" UAV at 100% dose compared to backpack sprayers. Wei et al. (2020) observed improved management of aphids and FAW with UAVs. Conventional sprayers struggle due to maize canopy structure, FAW habitat, crop height and large area demands. UAV downwash improves spray penetration (Zhan et al., 2022, Wongsuk et al., 2024). UAVs also save time 25 L/ha can be sprayed in 12-13 min versus 3-4 hours with a knapsack sprayer (Sambaiah et al., 2022). Increased efficiency in time, labour and spray intensity

Table 2. Cumulative efficacy of different insecticide and fungicide combinations delivered through drone and knapsack sprayer against FAW, *S. frugiperda* and BLSB, *R. solani* in maize during *rabi,* 2023-24

Treatments	Method of spray & Spray volume	Mean No. of larvae/ 10 plants					Leaf damage (%)					Davis scale of leaf damage	BLSB disease severity (%)
		PTC	After first spray	After second spray	Mean	ROC (%)	PTC	After first spray	After second spray	Mean	ROC (%)		
Chlorantraniliprole @ 12.5 ml/ ha + Azoxystrobin + Difenoconazole @ 25 ml/ ha	Drone spray @ 25 l/ ha	12.07a	3.44[a]	0.75a	2.10a	84.59a	51.23a	40.29a	37.25ba	37.01ba	52.84ba	2.65	0.00
Chlorantraniliprole @ 250 ml/ l + Azoxystrobin + Difenoconazole @ 500 ml/ l	Knapsack sprayer @ 500 l/ ha	13.30a	3.43[b]	0.92b	2.18b	84.01b	54.52a	43.34b	49.43b	39.59b	48.39b	2.75	0.00
Untreated control	-	13.04a	13.59 [c]	13.61c	13.60c	-	79.82a	80.10c	82.24c	79.98c	-	7.10	1.33

*Means with in a column followed by the same letter do not differ significantly as per DMRT (P=0.05) PTC= Pre-Treatment Count;
% ROC = Per cent Reduction Over Control; Davis scale of leaf damage: 1 - 9 scale

Table 3. Cost economics for the evaluation of insecticide + fungicide combinations delivered through drone and knapsack sprayer on maize

Treatments	Dose	Method of spray and spray volume	Grain yield (q/ ha)	Increase in yield over control (q/ ha)	Value of additional yield over control (Rs/ ha)	Avoidable yield loss (%)	Total cost of cultivation (Rs/ ha)	Gross returns (Rs/ ha)	Net profit (Rs/ ha)	C : B Ratio
Chlorantraniliprole @ 12.5 ml/ ha + Azoxystrobin + Difenoconazole @ 25 ml/ ha	0.5 ml /l+ 1 ml/l	Drone spray @ 25 l/ ha	46.86 [a]	26.56 [a]	47808	60.97 [a]	38810	84348	45538	1: 2.24
Chlorantraniliprole @ 250 ml/l + Azoxystrobin + Difenoconazole @ 500 ml/l	0.5 ml/l + 1 ml/l	Knapsack sprayer @ 500 l/ ha	40.55 [b]	20.25 [b]	36450	54.89 [b]	38710	72990	34280	1: 1.89
Untreated control	-		18.3 [c]	-	0.00	-	25000	32940	-	-

Means with in a column followed by the same letter do not differ significantly as per DMRT (P=0.05) has been reported by Shanmugam et al. (2024) and Shaw & Vimalkumar (2020), with UAVs effectively reaching maize whorls to control FAW larvae.

UAV-based spraying enhances droplet penetration and deposition in maize whorls through uniform aerial application and downward airflow, resulting in higher yield. Unlike conventional sprayers, it minimizes drift and ensures better coverage of the concealed whorl region where pests like fall armyworm reside.

CONCLUSION

The study demonstrated that drone spraying of insecticide + fungicide combinations, particularly chlorantraniliprole with azoxystrobin + difenoconazole was physically compatible, non-phytotoxic and provided superior control of FAW and BLSB in maize compared to conventional knapsack spraying. Drone application of pesticides ensured better droplet distribution, higher deposition, reduced pest incidence and increased maize yield and economic returns, highlighting UAVs as an efficient, time-saving, and effective precision tool for pesticide delivery and pest and disease management in maize.

AUTHOR'S CONTRIBUTION

The author Reshma, carried out the execution of all experiments, collected and organized the data, performed analyses and compiled the overall findings of the research. Coauthor Rajasri Mandali contributed to the conceptualization of the study and provided theoretical and academic inputs. J. Manjunath and P. Maheswara Reddy provided extensive support in drone operations and all related technical aspects throughout the study. Additionally, M. K. Jyosthna contributed significantly by assisting with the disease assessment studies, ensuring accurate observations and data collection.

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Received 10 September, 2025; Accepted 12 December, 2025