



Comparative assessment of drone and knapsack sprayers for pod borer (*Helicoverpa armigera*) management in chickpea (*Cicer arietinum*)

D N KAMBREKAR^{1*}, C P MALLAPUR¹, P U KRISHNARAJ¹, KARTIK NIDAGUNDI¹, NAVEEN V¹,
ARUNA J¹ and SURESH R JAMBAGI²

University of Agricultural Sciences, Dharwad, Karnataka 580 005, India

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ABSTRACT

Chickpea (*Cicer arietinum* L.) is an important pulse crop and its productivity is severely constrained by the gram pod borer [*Helicoverpa armigera* (Hübner)], one of the most destructive insect pests causing substantial yield losses. A field experiment was conducted during winter (*rabi*) season of 2022–23 at Main Agricultural Research Station, University of Agricultural Sciences, Dharwad, Karnataka using chlorantraniliprole 9.3% + lambda-cyhalothrin 4.6% ZC (200 mL/ha) and emamectin benzoate 5% + lufenuron 40% WG (60 g/ha) applied through a drone (20 L/ha spray volume) and a knapsack sprayer (500 L/ha). The study evaluated the bioefficacy of drone-based ultra-low-volume (ULV) insecticide application in comparison with conventional knapsack spraying for the management of *H. armigera* and its effects on pod damage, grain yield, phytotoxicity and the larval parasitoid *Campoletis chloridae*. Drone application significantly reduced larval populations throughout the observation period, resulting in lower pod damage (1.50–2.56%) and higher grain yield (14.20–16.10 q/ha) than conventional knapsack application (11.48–11.67% pod damage and 9.74–10.88 q/ha yield). No visible phytotoxic symptoms were observed, even at twice the recommended dose, while populations of *C. chloridae* were only moderately affected following insecticide application. The superior performance of drone application was attributed to improved spray coverage and canopy penetration under ULV spraying. As this investigation was conducted during a single season at one location, further multi-location and multi-season validation is required before recommending large-scale adoption of UAV-based insecticide application in chickpea.

Keywords: Drone, Natural enemies, Phytotoxicity, Precision agriculture

Chickpea (*Cicer arietinum* L.), the only widely cultivated species of the genus *Cicer* (Fabaceae), is an important source of protein for humans and animals, containing 20–30% protein, 35–40% carbohydrates and 3–6% oil (Gil *et al.* 1996). Its grains are also rich in calcium, magnesium, potassium, phosphorus, iron, zinc and manganese (Ibrikci *et al.* 2003). However, productivity is severely constrained by insect pests. In India, chickpea is attacked by nearly 57 insect species (Lal 1992), of which the pod borer, *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae), is the most destructive, causing 90–95% of the total pest damage (Sachan and Katti 1994). This polyphagous, multivoltine pest with diapause and high fecundity infests plants from the seedling stage through pod development, leading to 10–40% pod damage and heavy yield losses (Sharma 2005, Badariprasad *et al.* 2020).

Recent advancements in Indian agriculture have introduced unmanned aerial vehicle (UAV) as promising

tools for crop protection. Drone-based pesticide application improves efficiency by reducing labour, time, water and chemical use while minimising drift and farmer exposure to hazardous chemicals (Hafeez *et al.* 2023). Conventional knapsack or tractor-mounted sprayers consume higher volumes of pesticides and water, with significant wastage in the environment. In contrast, drones ensure better bio efficacy with reduced inputs and are increasingly seen as essential for precision farming. Long-term reliance on single insecticides leads to resistance and pesticide treadmill effects. Microbial pesticides like nuclear polyhedral viruses (NPVs) are alternatives that reduce resistance risks (Kambrekar *et al.* 2009). Pesticide mixtures also provide enhanced pest suppression *via* synergistic effects and can delay resistance development (Mallet 1989). In this context, the present study evaluated two combinations i.e. chlorantraniliprole 9.3% w/w + lambda-cyhalothrin 4.6% w/w ZC and emamectin benzoate 5% + lufenuron 40% WG against *H. armigera* in chickpea using drones and knapsack sprayers. Since drone sprays use only 20 L/ha compared to 500 L/ha in knapsack sprayers, this study also assessed potential phytotoxicity on chickpea and toxicity to the parasitoid *Campoletis chloridae* under field conditions.

¹University of Agricultural Sciences, Dharwad, Karnataka;

²ICAR-National Bureau of Agricultural Insect Resources, Bengaluru, Karnataka. *Corresponding author email: kambrekarndn@uasd.in

MATERIALS AND METHODS

The field experiment was conducted during the winter (*rabi*) season of 2022–23 at the Main Agricultural Research Station, University of Agricultural Sciences, Dharwad (15°07'N, 76°06'E; at an elevation of 678 m amsl), Karnataka, located in Agro-climatic Zone VIII of Karnataka. The experiment was laid out in a randomised block design (RBD) comprising seven treatments with three replications. Each experimental plot measured 20 m × 50 m and was planted with chickpea cultivar JG-11 at a spacing of 30 cm × 10 cm, accommodating approximately 33,330 plants/plot. A 10 m buffer zone was maintained between adjacent plots to minimise spray drift and treatment interference. All recommended agronomic practices prescribed by University of Agricultural Sciences, Dharwad, Karnataka were followed uniformly across treatments, except for plant protection measures.

Two foliar spray applications were imposed using insecticide formulations recommended for drone application by the Ministry of Agriculture and Farmers Welfare, Government of India (DA&FW 2022a, MoCA 2022). The treatments consisted of chlorantraniliprole 9.3% w/w + lambda-cyhalothrin 4.6% w/w ZC applied at 200 mL/ha (recommended dose); 400 mL/ha (double dose for phytotoxicity assessment); emamectin benzoate 5% + lufenuron 40% WG applied at 60 g/ha (recommended dose) and 120 g/ha (double dose) (Table 1). Recommended doses were also applied using a conventional knapsack sprayer for comparison, whereas an untreated control was maintained. Drone spraying was performed using a battery-operated UAV equipped with 10 L spray tank and four rotary atomising nozzles operating at adjustable speeds of 3,000–10,000 rpm (maximum 15,000 rpm). The system delivered an ultra-low-volume spray of 20 L/ha, producing droplets ranging from 70–250 µm with a deposition density of 30–50 droplets/cm². The drone was operated through an autonomous GPS-guided flight system at a constant height of 1.5 m above the crop canopy with an effective swath width of 4 m. Flight altitude was continuously regulated using the onboard altitude sensor, while spraying operations

were carried out by a DGCA (Directorate General of Civil Aviation) authorised pilot following the Standard Operating Procedure (SOP) for agricultural drone operations prescribed by the Government of India (DA&FW 2022 a, b). Plot boundaries were geo-referenced using GPS coordinates and autonomous flight paths were generated to ensure uniform application. Conventional spraying was carried out using a battery-operated knapsack sprayer fitted with a hollow cone nozzle operating at a pressure of 0.4 MPa and a discharge rate of approximately 1.20 L/min. Spray application followed the label-recommended spray volume of 500 L/ha, maintaining a walking speed of approximately 0.3 m/s to achieve uniform coverage.

Larval population of *H. armigera* was recorded from 10 randomly selected plants in each experimental plot one day before insecticide application and at 1, 5, 7, 10 and 15 days after each spray (DAS). The mean number of larvae/plant was calculated for each plot and used for statistical analysis. Pod damage was assessed by counting the total and damaged pods from 20 randomly selected plants in each plot and the percentage of pod damage was computed. Grain yield was recorded at harvest on a plot basis and converted to q/ha. Phytotoxicity was assessed in all insecticide treatments following both spray applications at 1, 5, 7, 10 and 15 DAS according to the standard phytotoxicity evaluation procedure described by Rao (1986). Visual symptoms, including leaf injury, chlorosis, necrosis, scorching, vein clearing, epinasty and hyponasty were recorded (Table 2). The effect of insecticide application on the natural enemy *C. chlorideae* was evaluated by recording the number of parasitoid pupae/m row length at 10 DAS.

The larval population recorded at each observation interval (1, 5, 7, 10 and 15 DAS) was analysed independently to account for the repeated measurements over time. Experimental observations obtained from the independent plot units were subjected to appropriate data transformation, wherever necessary, to satisfy the assumptions of normality and homogeneity of variance. The transformed data was analysed using analysis of variance (ANOVA) and treatment means were separated using Duncan's multiple range test (DMRT) at the 5% level of significance ($p \leq 0.05$). For ease

Table 1 Treatment details of the experiment

Insecticide treatment details	Formulation (mL/ha)	Spray equipment	Plot size (m ²)	Volume of spray solution (L/ha)
Chlorantraniliprole 9.3% w/w + Lambda cyhalothrin 4.6% w/w ZC	200	Drone	1,000	20
Chlorantraniliprole 9.3% w/w + Lambda cyhalothrin 4.6% w/w ZC	400	Drone	1,000	20
Chlorantraniliprole 9.3% w/w + Lambda cyhalothrin 4.6% w/w ZC	200	Knapsack	1,000	500
Emamectin benzoate 5% + Lufenuron 40% WG	60	Drone	1,000	20
Emamectin benzoate 5% + Lufenuron 40% WG	120	Drone	1,000	20
Emamectin benzoate 5% + Lufenuron 40% WG	60	Knapsack	1,000	500
Untreated check	-	-	1,000	-

Treatment numbers 2 and 5 for assessing phytotoxicity with two doses of insecticides. These treatments were not considered for bioefficacy and toxicity to natural enemies.

Table 2 Phytotoxicity scale used in the present investigation

Rating	Crop response/ Crop injury (%)	Verbal description
0	0	No symptoms
1	1–10	Very slight discoloration
2	11–20	More severe, but not lasting
3	21–30	Moderate and more lasting
4	31–40	Medium and lasting
5	41–50	Moderately heavy
6	51–60	Heavy
7	61–70	Very heavy
8	71–80	Nearly destroyed
9	81–90	Destroyed
10	91–100	Completely destroyed

of interpretation, the original (back-transformed) means are presented in the tables.

RESULTS AND DISCUSSION

Effect of drone-based insecticide application on *H. armigera* population: The initial *H. armigera* infestation did not differ significantly among treatments before insecticide application, with larval populations ranging from 3.8–4.55 larvae/plant, indicating a uniform pest distribution across the experimental plots prior to treatment imposition. Following the first application, significant differences in larval abundance were observed among treatments at all observation intervals (1, 5, 7, 10 and 15 DAS), demonstrating the effectiveness of both insecticide chemistry and application technique. At 1 day after the first spray, drone application of chlorantraniliprole 9.3% w/w + lambda-cyhalothrin 4.6% w/w ZC at the recommended dose (200 mL/ha) resulted in the lowest larval population (0.44 larvae/plant), followed by emamectin benzoate 5% + lufenuron 40% WG (1.55 larvae/plant). In contrast, the corresponding knapsack applications recorded substantially higher larval populations of 2.10 and 2.21 larvae/plant, respectively (Supplementary Table 1). A similar trend persisted during subsequent observations. Between 5 and 10 DAS, drone treatments maintained extremely low larval densities, whereas knapsack treatments retained measurable infestations throughout the observation period. Although slight larval

resurgence was observed at 15 DAS in both application methods, populations remained consistently lower under drone application than under conventional spraying. Similar treatment responses were observed following the second spray, where drone application maintained negligible larval populations throughout the evaluation period, while knapsack treatments continued to harbour significantly higher larval densities. The superior suppression of *H. armigera* under drone application was reflected in the overall larval reduction percentages (Fig. 1). Across both sprays and observation intervals, drone-applied chlorantraniliprole + lambda-cyhalothrin achieved a mean larval reduction of 99.85%, whereas emamectin benzoate + lufenuron achieved 97.95%. In comparison, the corresponding knapsack applications resulted in mean reductions of 93.32% and 78.36%, respectively (Fig. 2). Consequently, drone application provided an additional 38.55% and 39.98% improvement in larval suppression over conventional knapsack spraying for chlorantraniliprole + lambda-cyhalothrin and emamectin benzoate + lufenuron, respectively (Fig. 3, Supplementary Table 1 and 2).

The improved efficacy of drone application can be attributed primarily to enhanced spray deposition and canopy penetration achieved under ultra-low-volume (ULV) application (Dengeru *et al.* 2022). Unlike conventional hydraulic spraying, multirotor UAVs generate a downward airflow (rotor downwash) that transports spray droplets into the crop canopy, thereby improving droplet interception on concealed plant surfaces where *H. armigera* larvae actively feed. In addition, the smaller droplet spectrum and higher droplet density associated with rotary atomisers increase spray coverage while maintaining uniform distribution throughout the canopy. These characteristics enhance insecticide contact with target insects and reduce untreated microhabitats within dense crop stands.

Recent investigations have similarly demonstrated that UAV spraying improves droplet deposition, canopy penetration and biological efficacy against insect pests compared with conventional spraying. Dengeru *et al.*

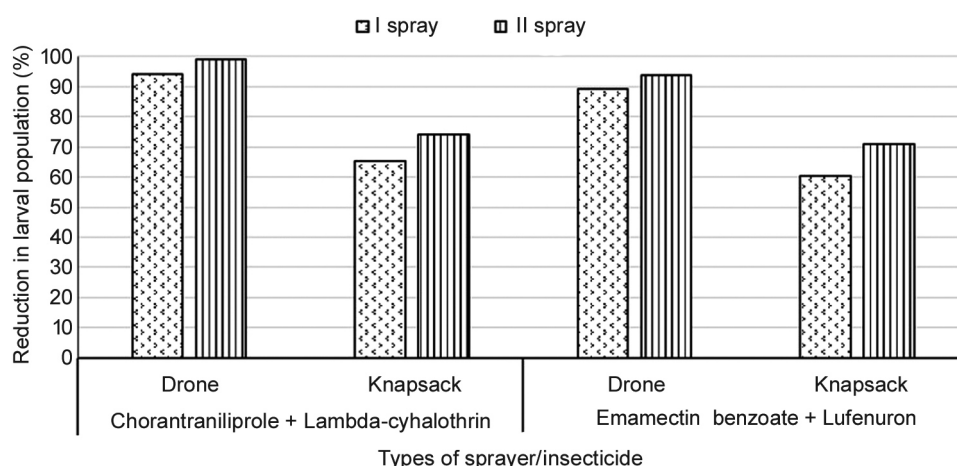


Fig. 1 Comparison of mean per cent reduction in the larval population (Drone vs Knapsack) (Mean of intervals).

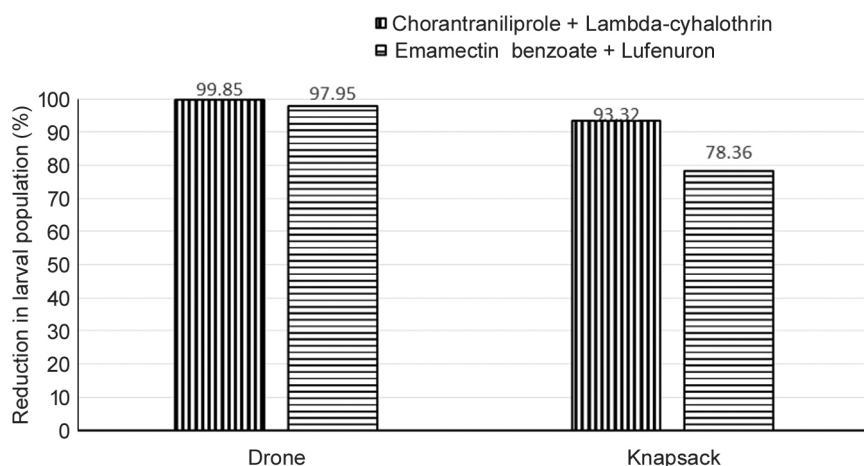


Fig. 2 Comparative efficacy of chlorantraniliprole + lambda-cyhalothrin and emamectin benzoate + lufenuron against pod borer in chickpea sprayed with drone and knapsack (Mean of sprays and intervals).

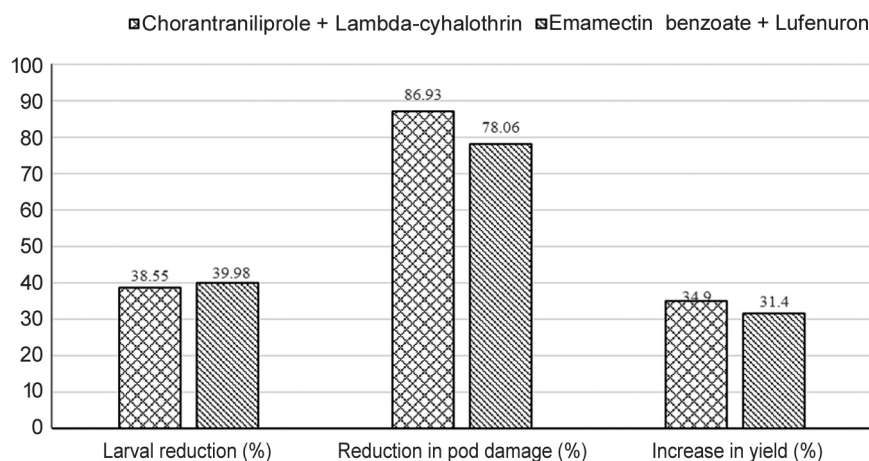


Fig. 3 Pest control advantage of drone over knapsack sprayer on pod borer larval reduction, reduction in pod damage and increase in yield of chickpea (Mean of intervals and sprays).

(2022) reported significantly greater droplet density and canopy coverage during UAV application in pigeonpea, resulting in superior suppression of *Helicoverpa* populations. Likewise, Wang *et al.* (2023) and Chen *et al.* (2024) also observed that rotor-generated airflow substantially improved spray penetration into middle and lower canopy layers, increasing insecticide deposition and biological performance while reducing spray losses. Similar improvements in pest suppression following UAV application have also been reported in soybean, rice and cotton, where enhanced deposition efficiency translated into greater control of concealed insect pests under field conditions. The present findings corroborate earlier reports demonstrating the effectiveness of chlorantraniliprole- and emamectin-based insecticides against *H. armigera* in chickpea and pigeonpea under conventional spraying. However, the present study further demonstrates that improvements in application technology can substantially enhance the biological performance of these insecticides without altering the recommended dose. Thus, the observed improvement

appears to arise from increased application efficiency rather than increased pesticide input.

Effect on pod damage and grain yield: The improved suppression of *H. armigera* achieved through drone application was reflected in significantly lower pod damage and higher grain yield. Drone application of chlorantraniliprole + lambda-cyhalothrin recorded only 1.50% pod damage and produced 16.10 q/ha, whereas emamectin benzoate + lufenuron recorded 2.56% pod damage with a grain yield of 14.20 q/ha (Table 3). In contrast, the corresponding knapsack treatments resulted in considerably higher pod damage (11.48 and 11.67%, respectively) and lower grain yields (10.88 and 9.74 q/ha). As expected, the untreated control exhibited the highest pod damage (24.56%) together with the lowest grain yield (6.45 q/ha). When the overall performance of the two application methods was compared, drone spraying reduced pod damage by 86.93% and 78.06% over knapsack spraying for chlorantraniliprole + lambda-cyhalothrin and emamectin benzoate + lufenuron, respectively, resulting in corresponding yield improvements of 34.90% and 31.40% (Fig. 3). The lower pod damage observed under drone application is closely associated with the more rapid suppression of early larval populations

immediately after insecticide application. *H. armigera* larvae cause irreversible injury by feeding directly on developing reproductive structures; therefore, early reduction in larval abundance substantially limits cumulative pod damage during crop development. Although conventional knapsack application also reduced larval populations, surviving larvae continued feeding during the interval between spray applications, resulting in greater cumulative pod injury. This explains why knapsack treatments exhibited substantially higher pod damage despite receiving the same insecticide dose. The higher grain yield recorded under drone treatments was therefore primarily a consequence of improved crop protection rather than any direct physiological effect of the application method. Reduced pod injury preserved reproductive sinks, resulting in greater pod retention and improved grain filling. Similar relationships between improved pest suppression, reduced pod damage and increased yield have been reported in chickpea by Kambrekar *et al.* (2012), Krishna Japur *et al.* (2016), Rani *et al.* (2018) and Prakash *et al.* (2021). More recently,

Table 3 Effectiveness of insecticides for the management of *H. armigera* and their effect on non-target organisms

Treatment	Dose (mL/ha)	Spray equipment	Pod damage (%) *	Number of <i>C. chloridae</i> pupae pmrl		Yield (q/ha)
				I Spray**	II Spray**	
Chlorantraniliprole 9.3% w/w + Lambda cyhalothrin 4.6% w/w ZC	200	Drone	1.50	1.62	1.35	16.10
Chlorantraniliprole 9.3% w/w + Lambda cyhalothrin 4.6% w/w ZC	400	Drone	1.00	1.15	1.00	16.68
Chlorantraniliprole 9.3% w/w + Lambda cyhalothrin 4.6% w/w ZC	200	Knapsack	11.48	1.65	1.38	10.88
Emamectin benzoate 5% + Lufenuron 40% WG	60	Drone	2.56	1.78	1.60	14.20
Emamectin benzoate 5% + Lufenuron 40% WG	120	Drone	1.65	1.21	1.07	14.28
Emamectin benzoate 5% + Lufenuron 40% WG	60	Knapsack	11.67	1.80	1.64	9.74
Untreated check	-	-	24.56	2.50	3.00	6.45
SEM±	-	-	-	0.11	0.13	1.11
CD ($p=0.05$)	-	-	-	0.38	0.38	3.37
CV (%)	-	-	-	12.04	10.47	14.44

*, Original values were subjected to arc sine transformation before analysis; **, Original values were subjected to $\sqrt{x} + 0.5$ transformation before analysis; pmrl, Per metre row length.

UAV-based insecticide application has also been shown to improve crop productivity in different crops through more efficient canopy coverage and enhanced biological efficacy compared with conventional spraying (Parmar *et al.* 2021, Wongsuk *et al.* 2024).

Effect on natural enemies and phytotoxicity: The abundance of the larval parasitoid *C. chloridae* varied significantly among treatments following insecticide application. The untreated control recorded the highest parasitoid population during both the first [(2.50 pupae/metre row length) and second sprays (3.00 pupae/metre row length)], whereas insecticide-treated plots showed comparatively lower populations irrespective of the application method. Among the recommended doses, drone application of chlorantraniliprole 9.3% w/w + lambda-cyhalothrin 4.6% w/w ZC recorded 1.62 and 1.35 pupae/metre row length after the first and second sprays, respectively, while emamectin benzoate 5% + lufenuron 40% WG recorded 1.78 and 1.60 pupae/metre row length. A further reduction in parasitoid abundance was observed with double-dose drone applications of both insecticides. The lower abundance of *C. chloridae* in treated plots is primarily attributable to the substantial reduction in *H. armigera* larvae, which serves as host for parasitoid development, rather than direct toxicity alone. Reduced host availability following effective pest suppression can naturally limit parasitoid populations. Nevertheless, the slightly lower parasitoid counts observed under double-dose treatments indicate that excessive insecticide exposure may adversely affect beneficial arthropods. These findings highlight the importance of adhering to recommended doses and integrating UAV-based insecticide application within an Integrated Pest Management (IPM) framework.

Drone technology should therefore be considered as a precision application tool that improves target-specific pest management while minimising unnecessary pesticide use, rather than as a replacement for biological control.

Phytotoxicity evaluation revealed that neither insecticide caused any visible injury to chickpea plants when applied through drones or conventional knapsack sprayers. No symptoms of leaf injury, wilting, vein clearing, necrosis, epinasty or hyponasty were observed at 1, 5, 7, 10 or 15 days after either spray, even when insecticides were applied at twice the recommended dose (Supplementary Table 3). These results indicate that ultra-low-volume drone application using a spray volume of 20 L/ha did not adversely affect crop safety despite the higher concentration of spray droplets compared with conventional spraying (500 L/ha). Similar observations have been reported by Prakash *et al.* (2021), who found no phytotoxic symptoms following the application of emamectin benzoate + lufenuron in pigeonpea.

This comparative assessment demonstrates that drone-based, ultra-low-volume (ULV) insecticide application provides superior control of *H. armigera* and yields higher chickpea productivity compared to traditional manual knapsack spraying. This enhanced efficacy is primarily driven by the drone's ability to achieve smaller droplet sizes, deeper canopy penetration and more uniform deposition across the foliage. Logistically, the UAV system presents a transformative alternative to labour-intensive knapsack sprayers by drastically minimising water consumption, reducing application time and overcoming physical terrain challenges such as waterlogged fields or dense crops. However, drone spray deposition is highly sensitive to operational and environmental variables, including wind speed, flight height and discharge rates, requiring strict

adherence to safety protocols and certified pilot operations. Consequently, while UAV technology represents a highly efficient crop protection strategy, multi-location and multi-seasonal validation, alongside rigorous investigations into its long-term ecological impact on soil-plant microbial biodiversity, are crucial before recommending its large-scale adoption.

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