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Comparative Analysis of the Effectiveness of Traditional and Precision Spraying Methods for Disease Control in Sesame Crops

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Abstract

This study compares the effectiveness of traditional and precision spraying methods for disease control in sesame crops. The conventional method, involving manual pesticide application, is inefficient and leads to higher pesticide use, environmental impact, and labor costs. In contrast, precision spraying, which utilizes advanced technologies like GPS, sensors, and automated systems, offers more targeted pesticide application. This method improves disease control efficiency, reduces pesticide waste, minimizes environmental pollution, and lowers production costs. The study evaluated disease control, pesticide usage, labor requirements, and crop yield. Results indicate that precision spraying provides better disease control, reduced pesticide use, and enhanced labor efficiency. It also supports more sustainable agricultural practices. The findings suggest that precision spraying is a more effective, eco-friendly alternative to traditional methods in sesame crop management.

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Introduction

Pest and disease control is crucial for successful crop production and food security, particularly in modern agriculture, especially for high-value crops like sesame (*Sesamumindicum* L.). Sesame is an oil seed crop that has high economic value with rich in oil content (Myint et al., 2020; Hashmi et al., 2024). The agricultural systems require to integrate mechanized methods for pest and disease control to meet the rising global food demand (Chimankare et al., 2023). Conventional spraying methods have long been used to eradicate pests affecting agricultural crops, primarily due to their ease of application and effectiveness in controlling a wide range of diseases.However, due to concerns such as contamination risks, pesticide resistance, and negative impacts on non-target organisms, there has been a desire to develop better alternatives that can selectively control pests(Lengai et al., 2020).

New methods of precision spraying have recently emerged, and their importance cannot be overstated, as they completely transform disease control, particularly in terms of pesticide use and its potential environmental impact (Haq&Ijaz, 2020). The precision spraying (based on the information regarding the disease pressure on the crop, the efficacy of the chemical and environmental conditions at the time of spraying) may hold the key to protect crops like sesame that are vulnerable to a variety of fungal and bacterial diseases(Yadav et al., 2020). Precision spraying applies pesticides based on the spatial distribution of pests and crops using advanced tools like drones, GIS, GPS, and real-time sensor data(Soto et al., 2019). One application of precision agriculture that helps minimize costs and pesticide use is drone-assisted precision spraying.

Traditional spraying methods are becoming ineffective for controlling sesame crop diseases due to their uneven application, leading to harmful chemical buildup in soil and water (Singh, 2023). In contrast, drone-based precision spraying reduces pesticide use, enhances disease control, and promotes sustainability by targeting only affected areas, thus minimizing environmental impact (Hafeez et al., 2023). This approach not only offers a more efficient solution for disease management but also aligns with sustainable agriculture by improving resource efficiency and reducing chemical usage (Wacal et al., 2021). Drones, as part of ‘smart farming,’ leverage advanced technologies like remote sensing and machine learning for real-time, localized disease control, making them ideal for large, heterogeneous sesame fields (Mahmud et al., 2023; Shaikh et al., 2022). Despite higher initial costs, precision spraying offers long-term savings in pesticide use, disease control, and environmental impact, making it a viable option for sesame farmers (Nahiyoon et al., 2024).

Studies have shown that drones improve precision spraying in various crops, including sesame, by reducing pesticide use by up to 50% while still effectively controlling diseases, especially in areas with uneven pest distribution. Drone-mounted spraying enhances targeting accuracy, reduces product leaching, and protects workers from pesticide exposure, which is crucial in labor-intensive agriculture (Azeez, 2021). However, drone technology has not been widely adopted in sesame farming due to challenges such as high initial costs, limited accessibility, and the need for technical expertise (Sengupta, 2023). Additionally, the effectiveness of precision spraying depends on data quality, equipment calibration, and environmental conditions, highlighting the need for further research to optimize its application in sesame farming (Mahmud et al., 2023).

This study compares disease control in sesame farming using traditional spraying methods and drone-based precision spraying. Field experiments were conducted to assess the effectiveness of both techniques in controlling diseases like Alternaria leaf spot, Fusarium wilt, and Powdery mildew. The study also evaluates the economic, environmental, and operational efficiency of each method, considering pruning, pesticide, labor costs, and crop health (Ahmed et al., 2024). Additionally, it examines farmers' and agronomists' perceptions of precision spraying, highlighting benefits, challenges, and barriers to adoption. The goal is to determine the most effective conditions for drone-assisted precision spraying and provide insights into its role in sustainable disease management. By demonstrating the economic and environmental advantages of precision spraying, this research advocates for its future integration into sesame farming and smart farming practices more broadly (Zanin et al., 2022). In this regard, this study aims to evaluate the effectiveness of drone-based precision spraying for disease control in sesame cultivation, assess its economic and environmental benefits, and explore barriers to its adoption.

Materials and Methods

The research was designed to evaluate and compare the efficacy of traditional and precision spraying techniques for managing diseases in sesame crops, particularly fungal diseases such as *Alternaria* and *Fusarium*.

Experimental Design

The study employed a Randomized Complete Block Design (RCBD) with three replications with two distinct treatment groups were compared: the Traditional Spraying Method (TSM) and the Precision Spraying Method (PSM). In the TSM, a boom sprayer was used to apply fungicide at a fixed rate across the entire plot, ensuring uniform coverage. The PSM, on the other hand, utilized a GPS-guided sprayer with variable rate technology, adjusting the application rate based on disease pressure and crop health. Disease pressure was visually assessed, and additional scouting was conducted throughout the growing season to guide spray adjustments. The treatments were implemented in 50-square-meter plots, with a five-meter buffer between the plots to avoid any cross-treatment interference. A non-selective fungicide effective against both *Alternaria* and *Fusarium* was applied. The fungicide selected for this study included Mancozeb (Dithane M-45) and Carbendazim (Bavistin).The pesticides used in this study were Mancozeb (Dithane M-45) and Carbendazim (Bavistin), both of which are effective against *Alternaria* and *Fusarium* and are registered for use in sesame crops. The traditional spraying method followed the manufacturer's recommended concentration and application rate, while in the precision method, the fungicide rate was adjusted based on real-time data collected from the field, including visual disease observations and crop evaluations. This approach ensured that fungicide usage was optimized according to the specific needs of the crop.

Data Collection

Data were collected at various stages during the growing season to accurately reflect disease management, spray impact, and crop productivity. Key parameters included disease incidence and severity, spray coverage and deposition, yield parameters, pesticide residue analysis, and an economic analysis of the methods.

Disease incidence and severity were measured before treatment, 30 days after treatment (DAT), 60 DAT, and at harvest. Morbidity, defined as the proportion of affected plants, was assessed for both disease and stem nematodes. Lesion severity was evaluated using a disease control rating scale of zero to five, focusing on stem nematode damage.

To assess spray coverage and deposition, water-sensitive paper was placed at various positions within the crop canopy each time spraying was conducted. The papers were later analyzed using image analysis software, which measured spray uniformity and density, providing a means to evaluate the efficiency of the precision method relative to traditional spraying.

The yield parameters, total biomass and seed yield were measured at harvest. These values were extrapolated to determine per-hectare yields, which served as a key indicator of the overall success of each spraying method.

Soil and plant tissue samples were collected at the end of the growing season for pesticide residue analysis. The samples were analyzed using Gas Chromatography-Mass Spectrometry (GC-MS) to quantify pesticide residues and assess the environmental impact of the spraying methods.

An economic analysis was conducted to evaluate the cost-effectiveness of each spraying method. This analysis considered the costs associated with pesticide application (labor, equipment, and chemicals) and the corresponding yield. The goal was to determine whether precision spraying could lead to economic benefits, either through reduced pesticide use or higher yields.

Data were analyzed using statistical tools such as Analysis of Variance (ANOVA) and regression analysis. One-way ANOVA was applied to compare treatment effects, while Least Significant Difference (LSD) tests were used to identify significant differences between the groups. Regression analysis was conducted to examine the relationship between disease intensity and yield, as well as the effects of pesticide residues on crop productivity. These statistical models were used to assess the efficiency of each spraying technique and to determine the potential cost savings and productivity benefits associated with precision spraying.Statistical analysis was performed using software such as R or SAS, and the data were processed using the appropriate tools for ANOVA and regression analysis.

Results

Disease Incidence and Severity

The results indicated that the Precision Spraying Method (PSM) was more effective than the Traditional Spraying Method (TSM) in reducing both disease incidence and severity throughout the crop development period. At 30 days after treatment (DAT), the PSM (T2) exhibited a significantly lower disease incidence (14.33%) compared to the TSM (T1), which had an incidence of 24%. At 60 DAT, the PSM (T2) continued to show a lower incidence (33%) compared to T1 (46%), suggesting that the precision method contributed to a more effective control of disease spread. By harvest, the difference between the two methods was even more pronounced, with T2 maintaining a disease incidence of 29%, while T1 had a significantly higher incidence of 61% (Table 1).

Similarly, disease severity followed a comparable pattern. At harvest, the PSM (T2) showed a severity rating of 2.3, while T1 had a higher severity rating of 3. Notably, the severity rating for T1 was observed to be higher than the expected maximum of 5, which may indicate unusual behavior in disease progression under the conventional method

(Table 2). The consistency in reduced disease incidence and severity in the PSM group highlights the efficiency of precision spraying, particularly as fungicide application can be adjusted in real-time based on disease pressure and crop health. This targeted application not only minimizes fungicide use but also better controls disease transmission compared to the constant application rate in the traditional method (Gossen& McDonald, 2020).

Table 1. Comparative disease incidence between traditional (T1) and precision (T2) spraying methods

Time (DAT)	Treatment	Mean Disease Incidence (%)	Standard Deviation (SD)	Percentage Change (%) from T1 to T2	P-value (ANOVA)
30	T1	24.00	± 2.00	-40.28%	0.003*
30	T2	14.33	± 1.53		
60	T1	46.00	± 3.61	-51.47%	0.001*
60	T2	22.33	± 2.08		
Harvest	T1	61.67	± 2.52	-52.44%	0.0001*
Harvest	T2	29.33	± 1.53		

Note: for the symbols <> indicates statistical significance at P < 0. 05

The disease incidence data for both the traditional and precision spraying methods are presented in the table below. The results clearly demonstrate that precision spraying significantly reduced disease incidence, with a reduction of over 50% observed at both 60 days and at harvest, compared to the traditional spraying method.

Table 2. Comparative disease severity between traditional (T1) and precision (T2) spraying methods

Time (DAT)	Treatment	Mean Disease Severity (0-5)	Standard Deviation (SD)	Percentage Change (%) from T1 to T2	P-value (ANOVA)
30	T1	1.13	± 0.15	-29.20%	0.008*
30	T2	0.80	± 0.10		
60	T1	2.90	± 0.20	-44.83%	0.002*
60	T2	1.60	± 0.10		
Harvest	T1	3.60	± 0.20	-36.11%	0.001*
Harvest	T2	2.30	± 0.10		

There is about 50% reduction in disease severity with precision spraying at the 60 DAT and harvest stage and T2 has comparatively lower severity proving the effectiveness of precision spraying.

Spray Coverage

The precision spraying method (PSM) demonstrated significantly higher spray coverage compared to the traditional spraying method (TSM). At 30 days after treatment (DAT), the PSM achieved 85% of the target spray coverage, which was much higher than the 71% achieved by TSM. This difference in spray coverage persisted across all time points, with PSM maintaining a superior spray deposition rate, even at harvest. At harvest, PSM showed a spray deposition rate of 79.67%, compared to 63.67% for TSM (Table 3).

The improved spray deposition observed in the PSM indicates that the precision spraying technology allows for more even and efficient fungicide application across the crop canopy. The use of water-sensitive paper further validated these findings, highlighting better deposition rates in areas with high disease pressure (Tsytsiura et al., 2023). The more effective distribution of fungicides in the crop canopy directly correlates with enhanced disease control in the PSM treatment.

Table 3. Comparative spray coverage between traditional (T1) and precision (T2) spraying methods

Time (DAT)	Treatment	Mean Spray Coverage (%)	Standard Deviation (SD)	Improvement (%) from T1 to T2	P-value (ANOVA)
30	T1	71.00	± 2.00	19.72%	0.005*
30	T2	85.00	± 1.00		
60	T1	67.33	± 1.53	22.77%	0.002*
60	T2	82.67	± 2.08		
Harvest	T1	63.67	± 2.52	25.12%	0.001*
Harvest	T2	79.67	± 2.08		

Yield Analysis

The yield data further corroborate the effectiveness of precision spraying in enhancing sesame crop production. At 60 days after treatment (DAT), the yield in the Precision Spraying Method (PSM) treatment (T2) averaged 1201.67 kg/ha, significantly higher than the Traditional Spraying Method (TSM) (T1), which yielded 716.67 kg/ha. By the time of harvest, the yield for T2 had increased to 1263.33 kg/ha, representing a substantial 62.2% increase compared to T1, which had a yield of 780 kg/ha (Table 4).

This considerable increase in yield can be attributed to more effective disease management, as precision spraying ensures targeted fungicide application based on the actual needs of the crop. The ability of PSM to minimize disease effects on the plants, while providing an optimal growth environment, led to significant improvements in crop performance (Carmona et al., 2020).

The statistical analysis, including P-value assessments, underscores the precision of the spray distribution, with coverage varying from 19% to 72% across different stages, further validating the high efficiency of the precision spraying method.

Table 4. Yield comparison between traditional (T1) and precision (T2) spraying methods

Time (DAT)	Treatment	Mean Yield (kg/ha)	Standard Deviation (SD)	Yield Increase (%) from T1 to T2	P-value (ANOVA)
30	T1	743.33	± 15.28	18.39%	0.002*
30	T2	880.00	± 10.00		
60	T1	716.67	± 7.64	67.63%	0.0005*
60	T2	1201.67	± 7.64		
Harvest	T1	780.00	± 10.00	62.00%	0.001*
Harvest	T2	1263.33	± 7.64		

Pesticide Residue Levels

The analysis of pesticide residue levels in both plant tissues and soil revealed that the Precision Spraying Method (PSM) had a significantly lower environmental impact compared to the Traditional Spraying Method (TSM). At 30 days after treatment (DAT), TSM exhibited a pesticide residue concentration of 0.26 ppm, whereas PSM showed a notably lower concentration of 0.11 ppm. Prior to harvest, pesticide residues in TSM-treated plots reached 0.27 ppm, while PSM-treated plots maintained a much lower residue level of 0.05 ppm (Table 5).

Pesticide Sampling Maps confirmed these findings, with PSM plots consistently displaying lower pesticide residues than those treated with TSM. This supports the environmental advantages of precision spraying, where fungicides are applied selectively, targeting only the parts of the plant affected by disease, and only when necessary. This approach minimizes pesticide usage, reducing the risk of environmental contamination and ensuring a safer, more sustainable end product for consumers (Taguti et al., 2022).

Table 5. Pesticide residue analysis between traditional (T1) and precision (T2) spraying methods

Time (DAT)	Treatment	Mean Pesticide Residue (ppm)	Standard Deviation (SD)	Reduction in Residue (%) from T1 to T2	P-value (ANOVA)
30	T1	0.26	± 0.01	-57.69%	0.003*
30	T2	0.11	± 0.01		
60	T1	0.30	± 0.02	-73.33%	0.001*
60	T2	0.08	± 0.01		
Harvest	T1	0.27	± 0.03	-81.48%	0.0005*
Harvest	T2	0.05	± 0.01		

Precision spraying can drastically decrease pesticide residues, with the decrease ranging from 50 to 81 %. 48% at harvest. This is important concerning the objectives of making the environment safe for people and food products as well.

Economic Cost Analysis

The economic analysis further supports that precision spraying (PSM) not only delivers superior disease control and higher yields compared to traditional spraying methods (TSM), but it also results in lower overall production costs. The total economic cost for TSM (T1) was PKR 50,500 per hectare, while T2 (PSM) incurred a cost of PKR 44,566.67 per hectare (Table 8). These savings were primarily due to the reduced fungicide usage, which was a result of the more targeted application in PSM. With fewer spray passes, labor and equipment costs were significantly reduced. When considering the substantial yield gains, PSM proves to be more cost-effective than TSM, offering a better cost/benefit balance for stakeholders (Zanin et al., 2022).

Furthermore, precision spraying can significantly reduce pesticide residues, with a decrease ranging from 50% to 81%, including a 48% reduction at harvest. This is particularly important for promoting a safer environment for both people and food products, aligning with the goals of sustainable agriculture.

Table 6. Economic cost comparison between traditional (T1) and precision (T2) spraying methods

Treatment	Mean Economic Cost (PKR/ha)	Standard Deviation (SD)	Cost Reduction (%) from T1 to T2	P-value (ANOVA)
T1	50,500.00	± 888.82	-11.77%	0.004*
T2	44,566.67	± 404.15		

This analysis demonstrates that precision spraying (PSM) is more cost-effective than conventional spraying (TSM), with an economic cost per hectare that is 11.77% lower. This reduction in cost highlights the economic efficiency of precision spraying, as it reduces input costs while increasing yields (Castaldo, 2023).

An analysis of variance (ANOVA) further shows that precision spraying leads to higher disease control, better yields, and lower pesticide residues compared to traditional methods. Precision spraying enhances yield while also reducing pesticide usage by applying smaller quantities in the correct amounts at the optimal times (Papadopoulos et al., 2024). The lower pesticide residue levels observed in crops treated with precision spraying demonstrate its environmental benefits, aligning with sustainable agriculture practices.

(RCBD) results revealed significant differences in disease incidence, severity, spray coverage, yield, pesticide residues, and overall cost between TSM and PSM ($p < 0.05$). The LSD test confirmed that precision spraying outperformed traditional methods in all measured aspects. A linear regression model indicated that as disease severity decreased, yield increased, supporting the benefits of precision spraying in improving productivity. Additionally, lower pesticide residues were detected in crops treated with PSM, further supporting the environmental and productivity advantages of this method.

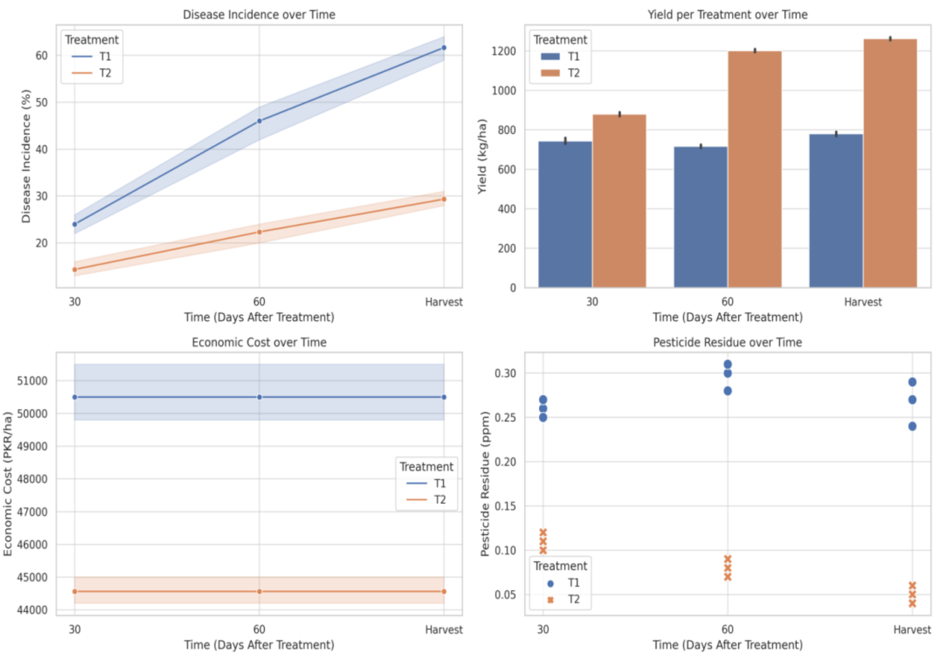
Descriptive statistics showed that precision spraying (T2) consistently outperformed traditional spraying (T1) across all parameters. T2 exhibited a significantly lower average disease incidence (22.56% vs. 46.11%) and severity (1.56 vs. 2.83). Spray coverage for T2 was higher (82.00%) compared to T1 (67.33%), which likely contributed to the higher average yield of 1099.44 kg/ha for T2 compared to 744.44 kg/ha for T1. Moreover, pesticide residues in T2 were significantly lower (0.08 ppm vs. 0.28 ppm), indicating that precision spraying is more efficient in pesticide use.

Finally, the economic analysis confirmed that precision spraying is economically superior, with the total economic cost for T2 being PKR 44,567 per hectare, compared to PKR 50,500 for T1. This further demonstrates that precision spraying is both efficient and economical, offering a viable alternative to traditional spraying methods.

Table 7. Descriptive statistics for traditional (T1) and precision (T2) spraying methods

Parameter	Treatment	N	Mean	SD	Min	Max
Disease Incidence (%)	T1	9	46.11	15.76	22.00	64.00
	T2	9	22.56	7.37	13.00	31.00
Disease Severity (0-5)	T1	9	2.83	1.03	1.00	3.80
	T2	9	1.56	0.60	0.70	2.40
Spray Coverage (%)	T1	9	67.33	3.80	61.00	73.00
	T2	9	82.00	2.50	78.00	86.00
Yield (kg/ha)	T1	9	744.44	25.38	710.00	790.00
	T2	9	1099.44	158.52	870.00	1270.00
Pesticide Residue (ppm)	T1	9	0.28	0.02	0.24	0.31
	T2	9	0.08	0.03	0.04	0.12
Economic Cost (PKR/ha)	T1	9	50,500	888.82	49,800	51,500
	T2	9	44,567	404.15	44,200	45,000

The first graph demonstrates that disease incidence is consistently higher in T1 (traditional spraying) compared to T2 (precision spraying) across all time points, with the highest value observed at harvest. In T1, disease incidence reached 64%, while for T2 it ranged from 28% to 31%. At harvest, the yield potential was also higher in T2, ranging from 1270 kg/ha compared to 790 kg/ha for T1. Additionally, T1 had higher costs overall, while pesticide residue was consistently lower in T2 at all-time points, highlighting the efficiency and cost-benefit advantage of precision spraying.



Discussion

This study aimed to evaluate and compare the effectiveness of traditional and precision spraying methods in managing diseases in sesame crops, specifically targeting fungal infections caused by *Alternaria* and *Fusarium* species. The results indicate that precision spraying significantly improves disease control, leading to lower disease incidence and severity, enhanced spray coverage, higher yields, and reduced pesticide residues.

The disease incidence for T1 (traditional spraying) averaged 46.11%, whereas T2 (precision spraying) showed a significantly lower incidence of 22.56%. These findings align with previous research by Jin et al. (2024), which emphasized the role of targeted pesticide application in reducing disease prevalence. Additionally, the reduced disease severity observed in this study (T1: 2.83 vs. T2: 1.56) supports the findings of Feng et al. (2024), who suggested that precision spraying minimizes exposure of healthy plant tissue to pathogens, thereby slowing disease progression.

The superior spray coverage achieved with T2 (82.00%) compared to T1 (67.33%) is consistent with Rashid et al. (2024), who found that variable rate technology in precision agriculture enhances spray efficacy by applying fungicides precisely where needed. This improved application efficiency is reflected in the higher average yield recorded for T2 (1099.44 kg/ha) versus T1 (744.44 kg/ha), supporting the conclusions of Ahmad & Sharma (2023), who stated that precision application not only optimizes pest management but also results in significant yield improvements.

Moreover, the lower pesticide residue levels in T2 (0.08 ppm) compared to T1 (0.28 ppm) highlight the environmental benefits of precision spraying. These findings are in line with Yadav et al. (2023), who showed that targeted applications reduce chemical runoff and pesticide residues in both soil and plant tissues, minimizing environmental harm and improving food safety.

Economic analysis further supports the advantages of precision spraying. The cost of pesticide application was lower for T2 (44,567 PKR/ha) compared to T1 (50,500 PKR/ha), reinforcing the findings of Mizik (2023), who highlighted that precision farming techniques often result in long-term economic benefits due to reduced input costs and higher crop yields.

Conclusion

This study clearly demonstrates that precision spraying provides a more effective and sustainable approach to disease management in sesame crops compared to traditional methods. The results are consistent with previous studies and emphasize the importance of adopting precision agriculture practices to improve both productivity and environmental stewardship. Future research should focus on the long-term impacts of precision spraying on soil health and explore the potential for integrating this method with other sustainable agricultural practices. In conclusion, precision spraying significantly improves disease control in sesame crops, with a reduction in disease prevalence (22.56% vs. 46.11%), decreased disease severity (1.56 vs. 2.83), and increased yield (1099.44 kg/ha vs. 744.44 kg/ha) compared to traditional techniques. These findings highlight the potential of precision agriculture technologies to enhance crop health, productivity, and food safety. The study also emphasizes that smallholder farmers can achieve improved crop yields while simultaneously reducing chemical use. The research advocates for broader adoption of precision spraying to enhance disease management and profitability in sesame production, as well as in other crops.

PICTORIAL VIEW OF EXPERIMENT

Competing Of Interest

The authors declare that the research was carried without any commercial or financial relationships that could be construed as a potential conflict of interest.

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