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RESEARCH ARTICLE

Efficiency analysis of drone-assisted pesticide application in paddy cultivation

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Abstract

This study evaluates the efficiency of drone-assisted pesticide application in paddy cultivation, focusing on time and water use efficiency compared to traditional manual spraying methods. The field trials, conducted in Needamangalam, Tamil Nadu, utilized the Tejas 10.1 drone for pesticide application over a 9 ac area. Findings revealed that drone spraying significantly outperforms manual knapsack sprayers in both efficiency and resource conservation. The drone covered 9 ac in just 1.2 hrs compared to 34.3 hrs required for manual spraying, demonstrating a 28.6-fold increase in time efficiency. Water consumption was reduced to one third with drone application requires only 72 L versus 240 L for manual spraying. Additionally, drone spraying minimized pesticide wastage through precise targeting, ensuring uniform coverage and reducing environmental impact. Drone application reduced the labour requirement to one sixth- this highlights the technology's potential to address labour shortage. However, widespread adoption faces challenges, including high initial investment costs, technical expertise requirements and regulatory restrictions. To promote accessibility, policy support, financial incentives and targeted training programs are recommended. This study underscores the potential of drones to revolutionize pesticide application in agriculture, making it more efficient, cost-effective and sustainable. Further research should explore AI integration and regulatory frameworks to enhance large-scale adoption.

Keywords: agricultural technology; drone spraying; paddy cultivation; precision agriculture; pesticide efficiency

Introduction

Global agriculture faces challenges in meeting the food demands of a population projected to reach 9 billion by 2050 while tackling climate change and resource constraint (1). Agricultural production must rise by 70 %, requiring adaptation strategies and innovations (2, 3). Climate change necessitates reduced greenhouse gas emissions and adaptive practices (3). Sustainable development requires balancing land use and adopting conservation technologies (2).

Smart technologies, big data and improved crop genetics provide solutions to these challenges (4, 5). Precision agriculture, automation and IoT enhance time efficiency, resources use efficiency and reduce environmental impact. CRISPR-based genome editing enables development of resilient and nutritionally enriched crops (5).

Success depends on applying multidisciplinary knowledge and developing institutional innovations (4). Future research should prioritize cost-effective, evidence-based policies to promote sustainable practices and protect environmental quality (2, 3).

Traditional methods of pesticide application, including manual spraying and tractor-based methods, often lead to inefficiencies such as uneven application, excessive chemical use and increased labour costs. These challenges highlight the need for innovative solutions that can enhance productivity while promoting sustainability.

Unmanned Aerial Vehicles (UAVs) are emerging as innovative solutions for precision pest management and agrochemical application in agriculture. These drones offer advantages over traditional methods, including early pest detection, targeted treatment and reduced chemical use. UAVs equipped with advanced imaging technologies can detect plant stress caused by pests, enabling precise and timely interventions (6). They provide more uniform spray distribution compared to conventional methods, addressing issues of uneven application and excessive chemical use. UAVs are particularly useful for crops like rice, cotton and sugarcane, where traditional spraying methods are less effective (7). The integration of UAVs with other technologies such as IoT and WSNs enhances precision agriculture applications, including crop monitoring and smart spraying (8).

Drone technology has demonstrated significant potential in various agricultural and environmental applications. In precision agriculture, drones equipped with RGB sensors can efficiently map and analyse forest plantations, providing accurate data on plant count, spacing and planting failures (9). For pest control, drones have been used to apply larvicides over large areas, effectively reducing mosquito populations in malaria-prone regions (10, 11). One study found that drone-sprayed treatments resulted in higher populations of beneficial soil microorganisms compared to traditional power sprayer methods. Another study reported pesticide reductions of up to 30 % using drone technology with artificial intelligence (12). study emphasizes drones' role in enhancing cultivation efficiency and reducing environmental impact through precise input application (13). Experiments demonstrated that using lecithin adjuvants with drone-based pesticide application reduced off-target drift by 2.62 to 3.16 times while improving deposition efficiency by up to 155 %. This allowed for a 25 % reduction in pesticide dosage without compromising control efficacy against rice blast disease (14). These findings collectively underscore the potential of drone technology to revolutionize agricultural practices, improving both efficiency and environmental sustainability. In India, drones have shown potential to address labour shortages and water scarcity (15). However, widespread adoption faces challenges such as high initial costs, technical complexity and regulatory barriers (16, 17). These obstacles particularly affect smallholder farmers and developing nations (17, 18). To overcome these barriers, researchers recommend government support, private-sector partnerships, targeted training programs and policy reforms to enhance accessibility and encourage adoption across all socioeconomic segments (15, 16, 18).

By drawing on these studies, this paper provides a comprehensive assessment of drone-assisted pesticide spraying in paddy cultivation. The analysis combines operational data from field experiment with Thejas 10.1 drone operations with broader insights from existing research to evaluate the technology's efficiency and economic feasibility. This approach aims to inform both policymakers and stakeholders about the practical benefits and challenges associated with drone technology in agriculture.

Objective

- To evaluate the time and water use efficiency of drone -assisted pesticide application in paddy cultivation.
- To compare time and water use efficiency of drone-assisted pesticide application in paddy cultivation

Materials and Methods

Study area and field trials

The study was conducted in Needamangalam, Tamil Nadu, India covering a total area of 9 ac of paddy fields (Fig. 1). The trial was conducted on December 7, 2024.

The Tejas 10.1 drone (Fig. 2) was used as the spraying drone designed for precision pesticide application. It features a 9 L tank capacity and a four-sprayer system with a maximum effective spray width of 3 to 5.5 m. The drone operates at a maximum flight speed of 7 m/s, ensuring rapid coverage of large fields. It is equipped with an advanced obstacle avoidance system, capable of detecting objects within a 1.5 to 30 m range, providing a 360° field view for enhanced safety. The water pump delivers a maximum flow rate of 1.5 L/min, optimizing pesticide distribution while minimizing waste. Powered by a high-capacity 9500 Mah battery, the drone ensures extended flight durations with efficient energy consumption.

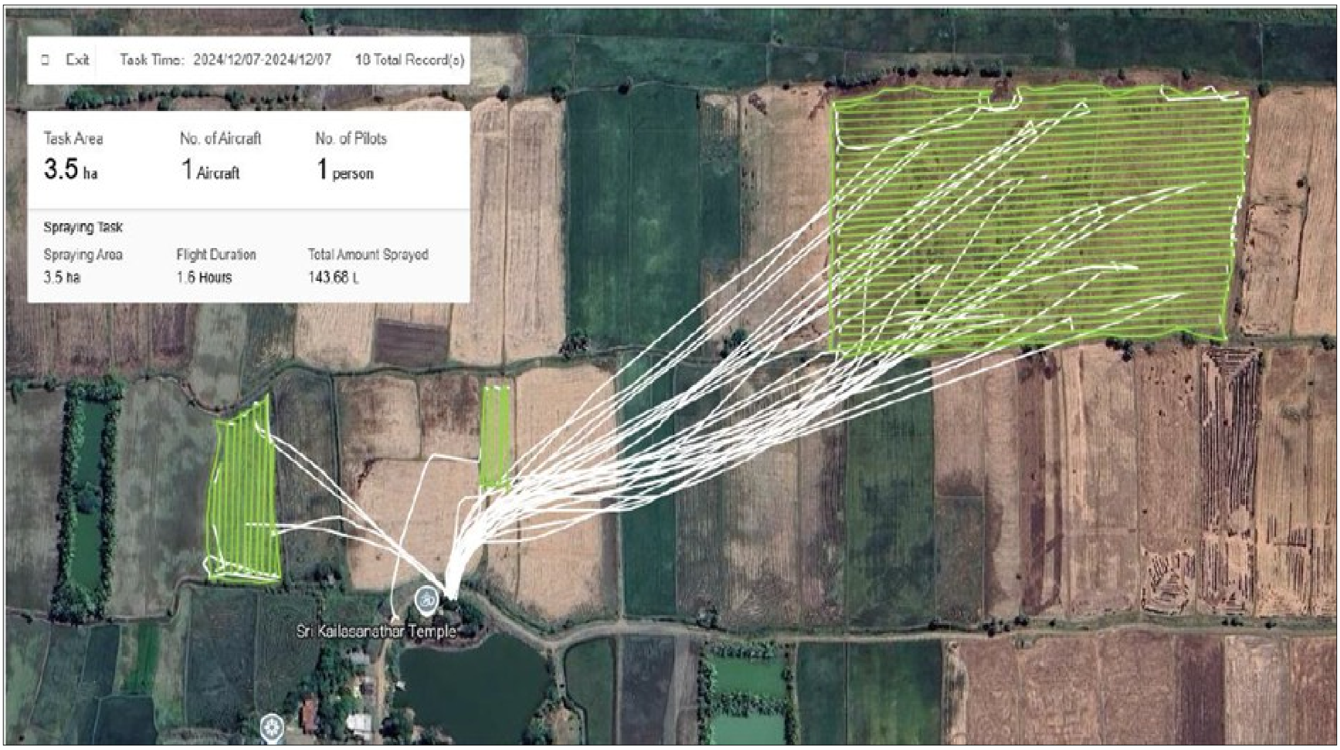

Fig. 1. Area covered by the drone.

Fig. 2. Drone: - Tejas 10.1.

- **Mapping the spraying area** using GPS.
- **Preparation of pesticide solutions**, including:
  - o Fungicide: Tricyclazole 75 % WP (600 g) + Azoxystrobin 11 % + Tebuconazole 18.3 % w/w SP (1 L) mixed in 4 L of water
  - o Insecticide: Cartap Hydrochloride 50 % SP (1kg) + Lambda Cyhalothrin 4.9 % CS (1 L) mixed in 4 L of water
- **Height of Spraying process**: 2 m

3.3 Data collection

The following parameters were recorded:

- Total area covered per flight cycle.
- Spray duration and pesticide consumption per acre.
- Comparison with conventional manual spraying in terms of pesticide use, labour costs and time efficiency.

Water use efficiency:

Water saving (%) =

$$\frac{(\text{Water used in manual spraying} - \text{Water used in drone spraying})}{\text{Water used in manual spraying}} \times 100$$

Time reduction (%) =

Time Efficiency:

$$\frac{(\text{Manual spraying time} - \text{Drone spraying time}) \times 100}{\text{Manual spraying time}}$$

Results and Discussion

Efficiency of drone spraying

- The drone sprayed 9 ac in approximately 3.5 hrs significantly reducing the time required compared to manual spraying.
- The application process was automated and uniform, ensuring even pesticide distribution.
- A significant reduction in pesticide wastage was observed due to precise targeting.

Economic and labour implications

- Drone-based spraying required minimal labour, (1 pilot) compared to conventional methods (3 labours for per day), 6 labours in total, reducing dependency on farm workers.

Time and water efficiency for drone vs. manual spraying

A comparison between the knapsack sprayer and the drone sprayer reveals significant differences in both time and water efficiency. The knapsack sprayer, with a tank capacity of 20 L and a flow rate of 7 L/hrs, covers approximately 0.75 ac per full tank. To spray a total area of 9 ac, a total of 12 tanks would be required, translating to a water usage of 240 L or 26.67 L/a. In terms of time, each tank requires 2.86 hrs to empty, resulting in a total spraying time of approximately 34.3 hrs for the entire area (Table 1).

In contrast, the drone sprayer demonstrates superior efficiency. With a smaller tank capacity of 9.5 L, the drone requires only two tanks per acre and operates at a significantly faster rate, taking just 4 min per tank. To spray 9 ac, the drone would require 18 tanks and a total water usage of 72 L, or (19) L per acre-substantially less than the knapsack method. The total spraying time for the drone is approximately 1.2 hrs, underscoring its advantage in both time and water conservation. This comparison clearly indicates that drone-based spraying systems can dramatically reduce resource consumption while enhancing operational efficiency in agricultural applications.

In agricultural pesticide application, efficiency in both time and water usage is crucial for optimizing productivity. A comparative analysis between a knapsack sprayer and a drone sprayer highlights significant differences in their operational effectiveness. The knapsack sprayer, with a tank capacity of 20 L and a flow rate of 7 L/hrs, covers 0.75 ac per tank, requiring 240 L of water to spray 9 ac at an application rate of 26.67 L/ac. The total spraying time for this coverage amounts to 34.3 hrs, as each tank takes 2.86 hrs to be fully utilized, necessitating 12 refills to complete the task. Conversely, the drone sprayer, featuring a 9.5 L tank with an application rate requiring two tanks per acre, significantly reduces water consumption to 72 L for 9 ac. The drone achieves this coverage in just 1.2 hrs, utilizing 18 tanks with each taking merely 4 min to spray. This stark contrast underscores the superior time and water efficiency of drone technology, demonstrating a 28.6-fold improvement in

Table 1. Comparison table of water and time efficiency

Sr. No	Method	Water used (L)/ 9 acre	Water use efficiency (Acres/Liter)	Time required (hrs)	Time efficiency (Acres per hrs)
1	**Knapsack sprayer**	240	0.0375	34.3	0.26
2	**Drone sprayer**	72	0.125	1.2	7.5

spraying speed and a 3.33-fold reduction in water usage compared to traditional knapsack sprayers. The findings suggest that integrating drone technology into large-scale farming can substantially enhance efficiency, minimize labour and conserve vital resources.

Challenges and limitations

- Regulatory restrictions on drone usage in agriculture need to be addressed for broader adoption.
- Initial investment and maintenance costs can be a barrier for small-scale farmers.
- Dependence on weather conditions and technical expertise for operation.

Conclusion

The comparison of spraying technologies highlights the substantial efficiency advantages of drone sprayers over traditional knapsack sprayers. In terms of time efficiency, the drone sprayer is approximately 28.6 times faster than the knapsack sprayer, completing the spraying of 9 ac in just 1.2 hrs compared to 34.3 hrs required by the manual method. This equates to a coverage rate of 7.5 ac/hr for the drone, whereas the knapsack sprayer manages only 0.26 ac/hr.

Water efficiency further underscores the benefits of drone technology. The drone sprayer requires only 72 L of water to cover 9 ac (19), in contrast to the 240 L consumed by the knapsack sprayer. This indicates that the drone uses 3.33 times less water per unit area, significantly reducing water usage and supporting more sustainable agricultural practices.

Overall, the drone sprayer demonstrates clear superiority in both time and water efficiency. Its rapid coverage rate and reduced water demand make it a highly effective and scalable solution for large-scale agricultural spraying, offering both economic and environmental advantages over conventional methods.

Recommendations

- **Policy support**: Governments should introduce incentives and subsidies for adopting drone technology in agriculture.
- **Farmer training**: Training programs should be organized to educate farmers on drone operation and maintenance.
- **Infrastructure development**: Research and development should focus on improving drone battery life and payload capacity for larger-scale applications.
- **Regulatory framework**: A standardized framework for drone-assisted pesticide application should be established to ensure safe and legal deployment.
- **Integration with AI**: Future studies should explore integrating drones with AI and IoT-based monitoring systems for real-time decision-making.

Authors' contributions

MR have prepared the final manuscript, MP have conceptualized the and followed the work throughout, VA have assisted in the writing of the manuscript, PSG have assisted in the calculation and statically, VC and PM have supervised the overall manuscript. All authors have read and agreed to the published version of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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