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Smart Farming and Agricultural Safety through Technological Advancement in Drone Spraying

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Abstract

The research investigates the transformative effects of drone technology on agricultural methodologies, with a focus on its application in Thai durian orchards, which play a pivotal role in Thailand's agriculture. It examines the efficacy of four distinct drone spraying methods in enhancing water distribution and minimizing chemical exposure. A significant discovery of the study is the effectiveness of using a reduced chemical volume of 125 liters per hectare, compared to 250 liters per hectare. This finding challenges traditional agricultural practices and underscores the benefits of precision technology in the application of treatments. By decreasing the volume of chemicals used, the study anticipates improvements in durian cultivation and significantly reduces farmers' exposure to harmful chemicals. This advancement represents a major leap towards safer, more sustainable, and efficient farming practices, positioning drone technology as a key player in the future of agriculture in durian farming.

Keywords: *Agriculture, Drone Spraying, Smart Farming, Environmental Sustainability*

1 Introduction

The rapid advancements in smart farming technologies have significantly transformed agricultural practices, enabling more efficient, sustainable and precise farming methods (Thongnim, Yuvanatemiya & Srinil (2023)). In recent years, the application of drones or unmanned aerial vehicles (UAVs) has emerged as a key innovation in precision agriculture offering unprecedented capabilities in crop monitoring, spraying and environmental management (Srinil & Thongnim (2024)). Drones equipped with advanced sensors and GPS technology have revolutionized the way farmers monitor crop health, apply fertilizers and pesticides and manage irrigation. One of the primary uses of drones in agriculture is for aerial imaging and mapping. Drones can capture high resolution images of fields, providing farmers with real time data on crop health, soil conditions and water distribution. Using multispectral and thermal sensors, drones can detect stress factors in crops, such as disease, pest infestations, nutrient deficiencies, long before they become visible to the naked eye. This data enables farmers to make timely decisions such as adjusting fertilizer application or initiating targeted pest control, thereby improving crop yields and reducing resource waste.

The method of precision farming has changed the way agriculture is practiced, with highly accurate and effective methods for managing crops. Drones have become a key player in this progress, offering a new way to apply important treatments such as pesticides, fertilizers, and water needed areas (Iost Filho et al. (2020), Velusamy et al. (2021)). The role of drone technology in agriculture, especially in spraying techniques, has attracted attention because of its potential to enhance the health of crops, increase amount of yields, and improve the efficiency of farms (Ah- mad et al. (2021), Hafeez et al. (2022)). However, the effectiveness of drone spraying is vary depending on several factors such as the type of spraying techniques and the environmental conditions. Therefore, it is important to carry out detailed research on different drone spraying techniques to find the best solution and make the most of these benefit.

Moreover, the use of drones for spraying treatments in agriculture offers good benefits to crops and to health and the environment. The spraying process, drones lessen the necessity for farmers to handle chemicals directly, thus reducing their exposure to harmful substances (Carvalho et al. (2020), Mahajan et al. (2023), Mandal et al. (2021)). This method also enhances precision in spraying, which helps to decrease chemical runoff, reducing the amount of pesticides and fertilizers that can affect nearby ecosystems. As a result, this protects local wildlife and water sources. Therefore, the adoption of drone technology in farming practices safeguards the health and safety of crops and farmers and greatly diminishes the environmental footprint of agricultural activities. This development represents a significant leap forward in promoting health in the agricultural sector and highlights the importance of innovative technologies in achieving sustainable environmental practices.

In Thailand, durian farming plays a vital role in the agricultural industry, greatly supporting the economy and reflecting Thai culture and culinary heritage. Known as the King of Fruits, durians require careful handling and specific farming techniques to satisfy the high-quality standards demanded by both local and international markets (Ketsa et al. (2020), Thongkaew et al. (2021)). The use of drone technology in durian farming is set to transform traditional agricultural methods by providing more accurate and efficient ways to apply treatments, thus improving the fruit's quality, increasing production, and making farming safer (Thongnim, Yuvanatemiya, Charoenwanit & Srinil (2023)).

This research focuses on the impact of drone spraying treatments in durian orchards, exploring how this technology could reduce the risks from chemicals, lessen the physical strain on farmers, and create safer work conditions. Moreover, this study aims to fill the existing knowledge gap by examining the effects of four distinct drone spraying treatments on durian crops and comparing them with those of an Air blast sprayer. A comprehensive experimental design assesses the impact of each treatment on key indicators, aiming to identify the most efficacious drone spraying strategies for adoption by farmers. These strategies are intended to enhance the quality and sustainability of durian cultivation and also to safe guard health simultaneously.

Therefore, this study will add valuable information to the growing field of precision farming technologies and their real world uses. By shedding light on the details of how effective drone spraying is and what it means for the health and safety of farmers, the results of this research will offer useful knowledge to both experts in agricultural technology and those who farm durians. This contribution will help guide more knowledgeable and precise farming practices in the area of precision agriculture.

2 Methodology

This study uses the DJI T40 drone to carry out tests with four different treatments to see how effective it is at applying pesticides and fertilizers compared to the usual method of using a 600-liter air blast sprayer on a durian farm. The purpose of these treatments is to look at factors like how well the drones cover the crops, if they can reduce the amount of chemicals used, the impact on the health of the farmers, and whether this method is cost-effective. By making this comparison, the re- search aims to find out the possible advantages of adding modern drone technology into traditional farming methods, especially focusing on health and environmental benefits. It seeks to uncover both the challenges and opportunities that come with using this advanced technology.

2.1 Site Selection and Data Collection

This study focuses on durian trees aged 9 years and 5 metres tall, located at a precise location denoted by the Plus Code P4G9+P2 in Salaeng, in the Mueang Chanthaburi District of Chanthaburi, Thailand. The chosen location for this drone spraying research initiative is within a durian orchard spanning

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JOURNAL OF MODERN COMPUTING AND ENGINEERING RESEARCH

approximately 1.92 hectares, which is part of the Fruit Development Center following the Royal Initiative in Chanthaburi Province, Thailand.

Figure 1: Drone sprayer at Work in a Durian Farm.

Figure 2: Air blast sprayer at Work in a Durian Farm.

2.2 Technology in Agriculture

This study uses the DJI T40 for testing in four treatments and compares it with a 600-liter air blast sprayer on a durian farm.

Fig 1 shows drone sprayers, unmanned aerial vehicles equipped with spray mechanisms, offer a highly flexible solution for distributing pesticides, herbicides, or fertilizers over crops from the air, allowing for precise application over specific areas. In addition, air blast sprayer (Fig 2), which are attached to air blast sprayer and include a tank, pump, and nozzles on a boom, operate on the ground, applying chemicals directly to crops as the air blast sprayer moves through the fields. This distinction highlights the aerial versus ground-based approaches to crop treatment, with drones providing precision and flexibility, particularly in difficult to reach areas, while air blast sprayer systems excel in their capacity to cover large, accessible fields efficiently.

In this research, by incorporating detailed planning for the drone spray route and setting the treatment parameters before applying water sensitive papers (WSP) (Fig 3 and 4). This involves conducting a comprehensive survey of the durian orchard to ascertain the layout, tree density, and canopy size, which informs the optimal flight paths for the drones. In this farm, the distance between lines is about five meters. Considering the leaf thickness is not substantial, the drone should fly at a height two meters to ensure effective coverage. Additionally, the optimal speed for the drone during the spraying process is 1.3 m/s to balance between coverage accuracy and operational efficiency (Kotarski et al. (2023)). WSP is employed to meticulously test the distribution patterns of water on durian trees, capturing how effectively these substances are ap- plied both on and under the leaves. Following the application, the study utilizes SnapCard, a sophisticated data analysis tool, to accurately assess and interpret the results (Nansen et al. (2015)). SnapCard's advanced algorithms analyze the color changes and coverage patterns on the WSP, enabling the quantification of the efficiency and uniformity of the spraying process (Ferguson et al. (2016)). This approach allows for a comprehensive evaluation of the spray techniques, contributing valuable insights into optimizing agricultural practices for durian farm.

2.3 Test Spray Solution Preparation

Water sensitive papers (WSPs) are strategically placed on, beneath, inside, and outside the leaves of durian trees, distributed across four treatment groups involving three distinct samples of trees. Consequently, each tree will have two WSPs attached: one on the upper surface of a leaf and the other on the underside, in addition to placements inside and outside the tree canopy. This comprehensive setup is designed to accurately capture and assess the coverage efficiency of drone- sprayed treatments (T).

Table 1: Details of drone spray treatments.

T	Speed	Nozzle Size	Volume
T 1	1.3	220	250
T 2	1.3	140	250
T 3	1.3	50	125
T 4	1.3	140	125

Table 1 presents four different drone spraying treatments, all test use the DJI T40 drone at a speed of 1.3 m/s, and different nozzle size and the volume of solution applied per hectare. Treatment 1 employs a 220-micron nozzle, with 250 liters per hectare, while Treatment 2 uses a 140-micron nozzle with the same volume. Treatment 3 decreases the nozzle size further to 50 microns and the volume to 125 liters per hectare, and Treatment 4 returns to the 140-micron nozzle and uses a reduced volume of 125 liters per hectare. This setup aims to explore the effects of nozzle size and solution volume on spray coverage and effectiveness.

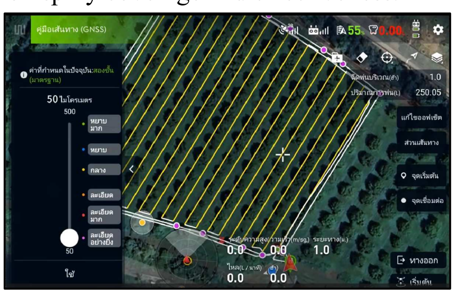

Figure 3: Planning the route and setting the treatment of drone spray.

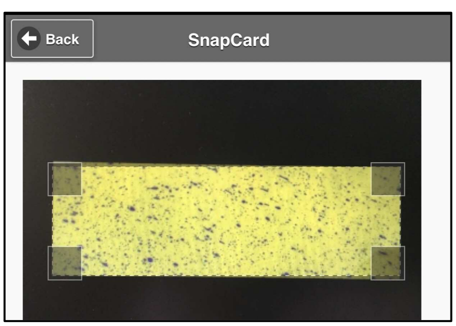

Figure 4: Using SnapCard to analyze water distribution.

2.4 Climate Conditions

Table 2 shows the environmental conditions recorded at the start times for four different treatments on a durian orchard. For Treatment 1, started at 10.26 am, the temperature was recorded at 35 Celsius with a wind speed of 17 km/hr. For Treatment 2, started at 11.16 am, experienced a small increase in temperature to 36 Celsius and wind speed to 19 km/hr, showing similar conditions with a big rise in wind activity that influence spray distribution. For Treatment 3, starting at 11.55 am, the temperature rose to 37 Celsius and wind speed to 21 km/hr, presenting challenges in maintaining spray precision due to increased thermal activity and wind movement. Finally, Treatment 4, started at 13.20 pm, recorded the same temperature of 37 Celsius but with the highest wind speed of 22 km/hr, marking the most challenging conditions for precise application, considering the daytime temperature and wind conditions that could lead to higher evaporation rates and drift. This data is crucial for evaluating the effectiveness and efficiency of drone spraying under varying climatic conditions, impacting the outcome of the agricultural practices.

Table 2: Environmental data for drone spraying treatments.

T	Start	Temp	Wind
T 1	10.26 am	35	17
T 2	11.16 am	36	19
T 3	11.55 am	37	21
T 4	13.20 pm	37	22

2.5 Exploratory Data Analysis (EDA)

A box plot (Majaw & Ahmed (2023)), enriched with the concept of percentage of max effective- ness, transforms into an instrument for visualizing and comparing the relative performance of various treatments and conditions. The effectiveness of each treatment as a percentage of its maximum observed effectiveness, it is possible to normalize the data across different scales. This normalization allows for direct comparisons even when the absolute measures of effectiveness significantly vary, streamlining the interpretation of complex datasets.

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JOURNAL OF MODERN COMPUTING AND ENGINEERING RESEARCH

The formula to calculate the percentage of maximum effectiveness for each treatment is given by

$$\%\ of\ Max\ Effectiveness = \left(\frac{E}{M}\right) \times 100,$$

where effectiveness value (E) is the observed effectiveness value of the treatment for a specific sample. Max effectiveness value for the treatment (M) is the highest observed effectiveness value for that treatment across all samples. In addition, the percentage of max effectiveness is the calculated value showing the effectiveness ofa treatment for a specific sample as a percentageof the maximum observed effectiveness for that treatment.

This method simplifies the interpretation of complex datasets, offering a clear visual framework for analyzing treatment efficacy, variability, and the influence of varying conditions on treatment results.

2.6 Comparative Analysis

After exploratory data analysis (EDA), a comparative analysis, potentially employing Randomized Complete Block Design (RCBD) (Shieh & Jan (2004)) will be performed to statistically evaluate the differences in treatment effectiveness across conditions. This approach aids in pinpointing treatments that are significantly more or less effective under various conditions. Although this analysis is based on hypothetical values, the re- sults serve as an illustrative guide on proceeding with real datasets once missing values are ad- dressed. The general formula for RCBD can be expressed as

$$Y_{ij} = \mu + \tau_i + \beta_j + \epsilon_{ij}$$

where Y_{ij} is the observed response for treatment i in block j, μ is the overall mean effect, τ_i is the effect of the i-th treatment, β_j is the effect of the j-th block, ϵ_{ij} is the random error term associated with the observation ij.

2.7 Data Analysis

The data analysis in this study is conducted using R to manage and process the data collected from the drone spraying experiments in durian orchards. The process begin by importing the data and checking for data completeness using the dplyr and tidyr packages which enabled efficient data manipulation. Moreover, the ggplot2 package is then employed to create graphs and conduct exploratory data analysis (EDA). The data analysis in this study is conducted using R to process the data from the chemical spraying experiments in durian orchards specifically employing the Randomized Complete Block Design (RCBD). Therefore, the agricolae package is utilized to perform the RCBD analysis, facilitating the evaluation and comparison of the spraying efficiency across different experimental groups.

3 Results

3.1 Insights on air blast sprayer

The air blast sprayer, tested under the same conditions as drone spray treatments, showed comprehensive coverage on WSP, indicated by a blue color spanning the entire area on a Durian leaf (Fig 5) and the ground (Fig 6). This suggests that air blast sprayer methods are highly effective in distributing water across durian farms. However, the results also highlight a significant drawback, the excessive use of chemicals and fertilizers. This leads to unnecessary financial expenditure on agricultural inputs and also poses a risk to the environment. Therefore, managing the quantity of chemicals and fertilizers to ensure they are used efficiently is crucial for durian farming.

Table 3 offers a comparative analysis of the efficiency between drone treatments and air blast application, focusing on two key parameters: time taken (minutes per hectare) and volume of spray used (liters per hectare). The air blast application requires 32 minutes per hectare, which is slightly higher than all drone treatments. In terms of volume usage, it was observed that the air blast sprayer required about 730 liters of water per hectare, whereas drone-based spraying, as demonstrated in this study, needed about 250-125 liters per hectare. This indicates that air blast sprayers consume approximately 3-5 times more water than drone sprayers.

Moreover, the adoption of new technology in durian farms must also consider the health and safety of farmers. When using air blast sprayers, operators are directly exposed to chemicals, posing potential health risks due to aerosolized sub- stances. In contrast, drone sprayers allow farmers to maintain a safe distance from the spray area, significantly reducing exposure risks. This distinction underscores the importance of integrating advanced technologies that prioritize both agricultural efficiency and farmer wellbeing in the modern era.

Figure 6: Water-sensitive paper was placed on the ground to assess the coverage by an air blast sprayer.

Figure 5: Water-sensitive paper was placed on a durian leaf to assess the coverage by an air blast sprayer.

Table 3: Comparative Analysis of the Efficiency of Drone Treatments and Air Blast Application.

T	Time	Volumn
T1(Drone)	30	250
T2 (Drone)	31	250
T3 (Drone)	28	125
T4 (Drone)	27	125
Air blast	32	730

3.2 Insights on Drone Sprayers from EDA

When considering effectiveness underneath leaves (Fig 7), Treatment 1 under out conditions shows the highest median effectiveness, which might suggest it is the best performer in terms of maximum potential effect. Treatment 2 shows better performance under in conditions with a higher median, but there is more variability.

Fig 8 offers a comparative view of the effectiveness of four treatments applied on leaves, expressed as a percentage of the maximum effectiveness for each treatment, with separate comparisons for the in and out conditions. Treatment 1 Exhibits the highest median effectiveness under in and out conditions among all treatments.

In all cases, the p-values are above the common alpha level of 0.05, indicating that the null hypothesis of normality cannot be rejected. This suggests that the data for both in and out conditions across all treatments do not significantly deviate from a normal distribution, based on the Shapiro-Wilk test. For RCBD, these results suggest that the assumption of normality is met. However, it is also important to note that RCBD is quite robust to violations of normality. However, the result indicates that there is no statistically significant difference in the means between different treatments and between the conditions (in and out), according to this block design analysis.

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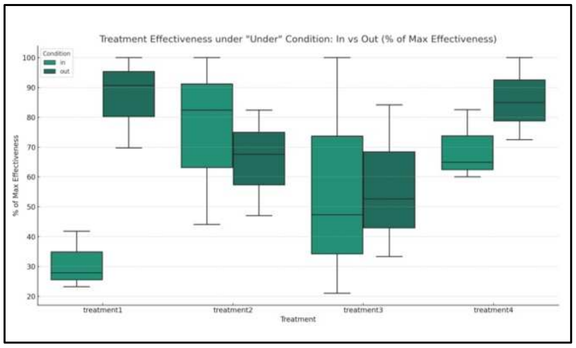

Figure 7: Box plot of treatment effectiveness under leaves: comparative effectiveness of four treatments applied underneath leaves, demonstrating ’In’ and ’Out’ conditions as a percentage of maximum effectiveness.

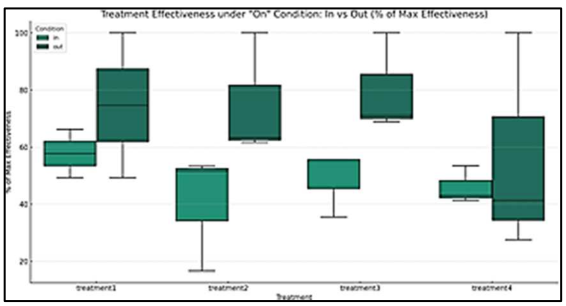

Figure 8: Box plot of treatment effectiveness on leaves: comparative effectiveness of four treatments applied on leaves, demonstrating ’In’ and ’Out’ con- ditions as a percentage of maximum effectiveness.

Table 4 indicates the differences among treatment levels are not statistically significant, as the p-value for the Treatment is 0.121, which is greater than the typical alpha level of 0.05. Moreover, the differences between the conditions (in and out used as blocks) show a p-value of 0.068. This is close to the significance level but still not below 0.05, indicating that the difference in conditions is not statistically significant at the 0.05 level, although it is marginally close.

Table 5 indicates for Treatment2, there is a statistically significant difference between in and out conditions, with a P-Value of 0.014. This suggests that the condition (in vs. out) has a significant impact on the response for Treatment2. For Treatment1, Treatment3, and Treatment4, the differences between in and out conditions are not statistically significant, as their P-Values are well above the 0.05 threshold. This focused analysis on the condition effect reveals that the impact of the condition is specific to the type of treatment, with a notable difference observed for Treatment 2.

Therefore, RCBD analysis revealed no significant overall difference between treatment effects at the conventional level of significance. This suggests that, on a broad level, the treatments might have similar impacts. The marginal p-value for the condition effect (in vs. out) suggested a potential difference that warranted further investigation. The subsequent t-test analysis for individual treatments showed a significant difference between in and out conditions for Treatment2, indicating that the effectiveness of this treatment could be influenced by the specific conditions un- der which it is applied. The significant result for Treatment2 in the condition-specific analysis (in vs. out) implies that this treatment’s effectiveness is sensitive to environmental or application conditions. Such a finding is crucial for operational considerations where conditions can be controlled or predicted.

Table 4: ANOVA table for RCBD

SOV	SS	df	F	P-value
Treatment	9.212	3	2.419	0.121
Condition	5.176	1	4.078	0.068
Residual	13.962	11		

Table 5: Pairwise t-test results for In vs. Out conditions

T	T-Statistics	P-Value
T 1	-0.632	0.625
T 2	-8.485	0.014
T 3	-2.429	0.244
T 4	-0.970	0.509

The experiment revealed that drone spraying uses more than 50% less chemical compared to traditional sprayers with drones requiring only 125-250 liters per hectare whereas air blast sprayers use up to 730 liters per hectare. Additionally, drone spraying can reduce the spraying time by 10% when compared to traditional methods. This reduction in chemical usage helps lower production costs and minimizes environmental impact and reduces health risks for farmers by limiting their direct exposure to harmful chemicals.

In addition, the effectiveness of treatments can vary based on these factors and insights from the study on condition effects can guide in aligning the choice of treatment with the farm's context. Consider the specific aspects of Durian farming such as the prevalent environmental conditions, the scale of operation and the specific challenges faced such as pests or diseases common to Durian trees. Therefore, emphasize the direct health benefits such as reduced exposure to harmful chemicals and practical gains like time savings, reduced labor costs, and increased crop yield and quality. Real life examples or case studies where drone technology led to tangible improvements can be particularly persuasive. Highlight the reduced environmental footprint of drone spraying, including less chemical runoff and better protection of biodiversity. This study discusses how precise application helps maintain ecological balance and supports sustainable farming initiatives.

4 Discussion

The detailed study on the application of drone spraying treatments in durian orchards, particularly in the context of chemical use optimization, underscores this shift vividly. It reveals that employing drones for chemical application not only enhances the precision and efficiency of treatments but also significantly reduces the necessity for larger volumes of chemicals traditionally used. Specifically, the findings suggest that a reduced volume of 125 liters per hectare is sufficiently effective, challenging the application rate of 250 liters per hectare. This efficiency is attributed to the drones' ability to target treatments more accurately, thus minimizing waste and ensuring that the chemicals are utilized where they are most needed.

Moreover, the research highlights the crucial role of environmental conditions in the effective- ness of drone applied treatments and advocates for the strategic adjustment of drone operation parameters to maximize coverage and efficacy (Zorbas et al. (2016)). By focusing on the optimization of nozzle size (Yu et al. (2020)), flying height (Han & Bae (2018)), and speed (Nordin et al. (2021)), the study demonstrates that it is possible to achieve optimal results with lower chemical volumes, aligning with the goals of reducing environmental impact and safeguarding farmer health. The implications of these findings are profound, offering pathways to substantial cost savings for farmers and promoting a shift towards more environmentally responsible agricultural practices. This paradigm shift not only supports the health and safety of farmers by reducing their exposure to chemicals but also contributes to the broader objectives of sustainable agriculture by minimizing chemical runoff and preserving the integrity of ecosystems surrounding farmlands.

Therefore, drones can be programmed to apply sprays precisely where needed, minimizing the amount of chemicals used. This precision reduces the risk of over-application and prevents chemicals from affecting unintended areas, thereby protecting nearby crops, water sources, and wildlife. Drone technology can cover large areas quickly, ensuring timely application of treatments that would otherwise require considerably more time and labor (Carvalho et al. (2020), Subramanian et al. (2021)). This efficiency is crucial during critical periods of crop growth or pest infestation. Traditional spraying methods often expose farmers to chemicals, posing health risks from inhalation or skin contact. Drones eliminate the need for farmers to be in close proximity to the chemicals, significantly reducing their risk of exposure. Due to their precision, drones can apply chemicals in optimal quantities, decreasing the overall volume of pesticides released into the environment (Shaw & Vimalkumar (2020)). This approach not only is safer for the farmer but also supports sustainable farming practices.

Although this study demonstrates the effectiveness of drone spraying in durian orchards, there are several limitations that should be considered. The small sample size used in the experiment may lead to some inaccuracies when comparing the results to larger and more diverse areas. Additionally, the study focuses solely on durian, which limits the applicability of the findings to other crops with different growth patterns and requirements. However, the integration of drone

JMCER
JOURNAL OF MODERN COMPUTING AND ENGINEERING RESEARCH

technology in agriculture holds significant potential for increasing efficiency, reducing costs, minimizing chemical use and enhancing farmer safety in the future. Furthermore, drone usage supports environmental sustainability by reducing the release of chemicals into nature. Despite these benefits, there are challenges such as the high initial costs of adopting drone technology which may be a barrier for small scale farmers as well as technical issues related to operating and maintaining drones in adverse environmental conditions such as strong winds and rapidly changing weather. Addressing these challenges will be crucial to ensuring the sustainable use of drone technology in agriculture moving forward.

5 Conclusion

This study on drone spraying technology in Durian orchards underscores a significant advancement in agricultural practices, revealing its potential to enhance efficiency, and environmental sustainability. Incorporating these insights can provide a strong foundation for advocating the use of 125 liters per hectare in drone spraying, offering a compelling argument for reducing chemical use in agriculture through technological innovation. Highlight the study's findings that demonstrate the efficacy of reduced chemical volumes in achieving desired agricultural outcomes without compromising crop health or yield. Additionally, discuss the implications for environmental sustainability, reinforcing the argument that technology can lead to more efficient, safer, and environmentally friendly farming methods. In addition, it highlights the technology's role in reducing farmers' exposure to harmful chemicals, thus safeguarding their health through precise application of treatments. This adoption is aimed at improving crop yield and quality while promoting safer and more sustainable farming practices in Thailand. As agriculture evolves towards precision and sustainability, drone technology emerges as a pivotal tool in realizing these goals, especially in high value crops such as Durian where the balance between productivity and environ- mental stewardship is critical.

Future research should explore the scalability of drone technology across different crop types and regions, as well as investigate the long term economic benefits for small and large-scale farmers. Additionally, there is a need to address technical challenges such as drone maintenance, operational limitations under varying environmental conditions and the initial cost barrier for widespread adoption. These areas of investigation will be crucial for further advancing the role of drone technology in promoting sustainable and efficient smart farming.

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Biography

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