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Original Article

Spray Performance Case Study of an Agriculture Drone in Pineapple Plantation

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Abstract - *The quality of spraying or efficacy is important in agriculture as it impacts the environment and the cost of operation. Over-application of a product will affect the surrounding area, leading to runoffs and wastage. Plants require a specific amount of product for optimum growth, which applies to fertiliser and herbicide use included in this study. A case study at a pineapple plantation was conducted, referencing both the product direction of use and feedback from the farmers at the plantation based on the agriculture strategies practised. Using a quadrotor drone with a 16-litre capacity with two types of nozzles (flat and cone) for the herbicide and fertiliser application with flight parameters of 2 meters in height and 2-4 m/s flight speed resulted in a coverage of 20-30 L/acre. Documentation of the practice is recorded here for reference to the practice in Malaysia's pineapple plantation.*

Keywords - *Agriculture drones, Drone spraying, Experiments and case studies, Pineapple plantation.*

1. Introduction

Malaysia is located in the equatorial region with abundant sunlight and fertile soil, an ideal location for a nation invested in agriculture. The three common agriculture industries of the country are Palm Oil, Paddy, and Pineapple [1]. An area of 17,802 hectares (ha), according to the Malaysia Pineapple Industry Board (MPIB), with 537,231 Metric Ton (MT) and 933,439 Ringgit Malaysia (RM) in value from the industry, is contributed to the nation, Table 1-3 [2], [3]. The industry is growing to fit the National Pineapple Industry Development Plan 2019-2025 by the Ministry of Agriculture and Food Security Malaysia. Using drones synergises with technology and quality conformity in one of the five core strategic plans outlined in [4].

According to the case study by [3], the majority of energy used to operate the field is in fertilising (54.61%), hormone spraying (4.61%), and weeding (0.76%), a total of 59.98%, followed by 21.87% for the planting and 14.62% in land preparation. Hence, drones alleviate and optimise issues in crop spraying to improve yield and reduce operating costs. Complementing the previous study, up to 60% of energy was used for field maintenance, and a 68.1% technical efficiency was found [5]. The remaining 31.9% is lost through inefficiency and risk borne from the agricultural practice. The inefficiency can be mitigated with modern technology at every step of the process, from planting, fertilising, pesticides, and hormones to labour utilisation. The author recommends spreading and implementing efficient and effective farming practices and utilising modern machines in production. Effectiveness and efficiency are two of the concerns in managing resources, and on the business side is profitability. A study on the profitability of the pineapple industry shows that it is at 1.72 [6]. The business is profitable, but implementing mechanisation and efficient resource management would increase the benefit-to-cost ratio.

Table 1. Malaysia pineapple agriculture 2022 MPIB statistics

Area of plantation	Plantable area	Output
17,802 ha	14,275 ha	537,231 MT
Output value	**Ratio of output**	
RM 933,439 M	37.63 MT/ha	

Table 2. Pineapple distribution by type

Josephine	Morris	MD2	Others
41.5%	30.8%	19.9%	7.8%

Table 3. Pineapple production statistics in malaysia

	MT	RM
Ornamental	65,281.00	10,711,505
Fresh	16,428.40	22,258,649
Canned	28,045.29	987,800,113
Processed	6,598,496.56	82,657,722
Juice	868.56	3,267,886
Total	6,709,119.81	1,106,695,875

One of the most effective resource management strategies is precision farming. A report by the Malaysian Agricultural Research and Development Institute (MARDI) uses Variable Rate Technology (VRT) in paddy to manage fertiliser usage [7]. The two technologies in VRT are either map-based or sensor-based approaches. A map with a preloaded dispense rate is loaded onto the machine, and the latter uses an onboard sensor to determine the rate, enabling the machine to be dynamic but at a cost. Optimising the use of resources is in line with the study's objective. This leads to the need for mechanisation in the pineapple industry; another research study by MARDI is implementing it as a part of smart agriculture [8]. A complement between industry 4.0 sensors in the field and mechanisation to reduce the input cost. Enabling better management in planting, crop maintenance, and harvesting.

Noting the previous energy usage in [3], a cyclic lifecycle was addressed by MARDI. Start with land preparation, cultivation, crop maintenance, harvesting, and post-harvest before repeating the cycle. Mechanisation exists every step of the way, but both studies emphasised resource intensiveness in crop maintenance. This leads to exploring the use of Unmanned Aerial Vehicles (UAVs) in precision agriculture. Supported by a paper showcasing the use of UAV in an aerial survey of an agricultural plot to determine the terrain and monitor crop growth [9]. A starting point before a more involved UAV is integrated into the system.

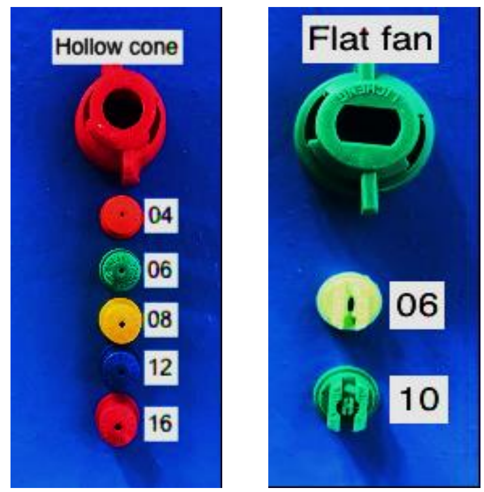
Furthering the work explored in this paper is to expand the understanding of configurations specific to pineapple agriculture. A study was made to study the drift and deposition of UAVs by varying the height and speed of flight [10], and a 15-55% spray drift was observed. Through meteorological data, the drift was between 3.7 and 46.5 m from the flight path. The paper's data was insightful regarding particle drift and behaviour, but correlation to the acceptance and accordance of the practising farmers was lacking. Hence, the study contributes more information on the configuration and parameters of the UAV following pineapple farming practices in Malaysia. Consideration of the MPIB farming practices by theory [11]. Evaluation through demonstration and experiments with the local farmers. Correlating both with industrial guidelines on the effective use of the sprayer. Concluding on acceptable parameters for UAV fertilising and spraying in Malaysia pineapple agriculture.

2. Methodology

The case study for the test was performed using a quadcopter drone with a 16 L payload and a 0.85 m nozzle spacing. The test varied the speed and altitude between 2-5 m/s and 2-5 m from the terrain. With a configuration to service both fertiliser and herbicide using flat spray and hollow cone configuration shown in Figure 1. The case study involves three criteria: the MPIB guideline, pineapple farmer's field practice, and theoretical analysis based on spray specifications.

The workflow is as follows:

1. Conduct an initial case study of fertilising and herbicide practices in pineapple agriculture.
2. Field and site visit of the study plot for the case and discussion with the farmers.
3. Mapping of the site for autonomous operations.
4. Trial with feedback from the farmers observing the operations.
5. Analysis and comparison of the practice and theory.
6. Conclusion and recommendations for drone operation in pineapple spraying.



(a) (b)

Fig. 1 (a) Hollow cone (b) flat spray

Table 4. Fertiliser and herbicide mix in pineapple application [11]

Pineapple Fertilizer Mix per 18 L ratio from 100 kg of PFM	
Ammonium Sulphate	72 kg
Christmas Island Rock Phosphate (CIRP)	1 kg
Muriate of Potash (MOP)	27 kg
Bordeux Mix 1 per 18 L	
Chalk	640 g
Ferrum Sulphate	21 g
Zinc Sulphate	42 g
Copper Sulphate	42 g
Bordeux Mix 2 per 18 L	
Chalk	640 g
Ferrum Sulphate	21 g
Zinc Sulphate	42 g
Copper Sulphate	42 g
Urea	640 g
Etherpon Urea per 18 L	
Ethepon	20 mL
Urea	180 mL
Urea per 18 L	
Urea	700 g
Weeding per 18 L	
Paraquat	50-100 mL
Glyphosate	80-100 mL

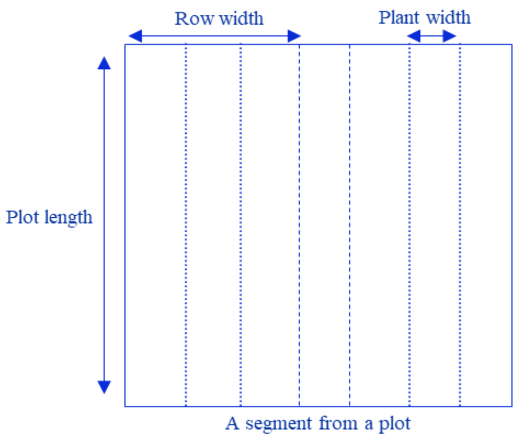


Fig. 2 MPIB pineapple plot guide

3. MPIB Agriculture Practice

Agriculture practice based on guidelines by the MPIB for peat soil takes 54 weeks from planting to harvest, 55 weeks if including seedlings preparations with a plant density of 14,569 plants per acre or 36,00 per hectare. The guidelines suit Moris, Josaphine, Gandul, Sarawak, and N36; the recommended spacing is 90 cm between rows, 60 cm between plants (row width) in the row, and 30 cm along the row (plant width) shown in Figure 2. The guideline has three types of products: fertiliser, herbicide, and budding agent. Fertiliser for pineapple has three types of mix, Table 4. Pineapple Fertilizer Mix (PFM), Bordeaux Mix 1 and 2. An Etherpon Urea for the budding agent mix. There are two types of mix for weeding: Paraquat for general weeding and Glyphosate for tall grass clearing. The 55-week growing period utilises the product mix at different stages of plant growth, with a target volume per plant. The product application is applicable throughout the day except for rain. The budding agent is applicable either during the morning (7 am-10 am) or afternoon (5 pm-7 pm).

4. Case Study

Starting the case study, referencing MPIB agriculture practice in the previous section, with a site visit and preparation of the test site is as in Figure 3. A quadrotor drone was used to conduct the fertilising (plot 1) and herbicide spray (plot 2) with feedback from the farmer on the execution, correlating the guidelines and farmer experiences. A field map was made in Figure 4 for automation during the spraying process. The study started with the smallest nozzle size (flat spray 06 and hollow cone 04) at 3 m altitude for fertilising and herbicide, following Tables 5 and 6. Clogging was observed during the fertilising trial due to the chalk in the Bordeaux mix. Despite the fine chalk powder, the mix was not homogeneous and settled in the tank over time. The nozzles with filter and fine-sized spray tip 10 are observed in Figure 6. The problem was mitigated by removing the filter and using a large flat spray tip 06. No problem was identified with herbicide spray except for the farmer's preference for the hollow cone spray with a fine mist 06.

Table 5. Application cycle of the product

Week	Type	Mixture	Value
3	Herbicide	Weeding	As necessary
6	Fertiliser	Bordeaux Mix 1	50 mL/tree
12	Fertiliser	PFM	14 g/tree
18	Fertiliser	Bordeaux Mix 2	100 mL/tree
24	Fertiliser	PFM	14 g/tree
34	Fertiliser	PFM	14 g/tree
36	Budding agent	Ethepon Urea	30-50 mL/tree
55	Fertiliser	Urea	50 kg/ha

Table 6. Experiment specification

Experiment type	Fertilising	Herbicide
Payload (Liter)	16L Bordeaux Mix	16L Weeding
Nozzle	Flat fan (06, 10) Hollow cone (04, 06, 08, 12, 16)	
Altitude (meter)	1-3	
Flight speed (m/s)	2-4	
Flight pattern	Rectangular (zig-zag)	
Distance (meter)	150	

The drone can hold altitude with elevation data from the mapping process. Execution, however, was not feasible due to the elevation fluctuation during the flight, deviating by 0.25 m. The farmers were concerned about the plant's safety from a potential collision when testing it at 1 m and 3 m. The spray is similar to Figure 5(a). Hence, a fixed altitude of 2 m was set throughout the experiment.

The experiment also conducted tests at various speeds (2-4 m/s), and the farmers were satisfied with the 3 m/s as the best speed, Figure 5(b). The coverage by the drone flying at 4 m/s was too faint, Figure 5(a), and there were concerns about adequate coverage on the plant. The 2 m/s was dense, as shown in Figure 5(c), and considering the flight capability of the drone of 7 min flight time to dispense 16 L, it was not feasible.

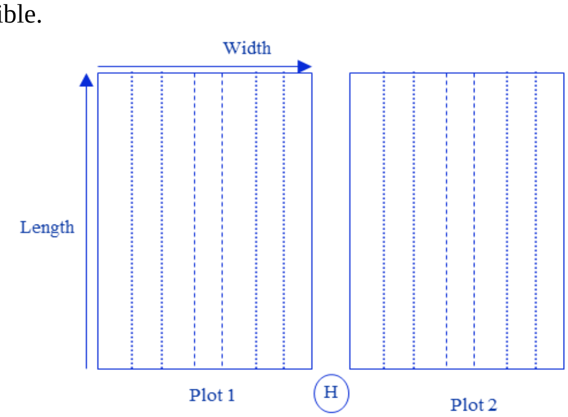


Fig. 3 Test field layout

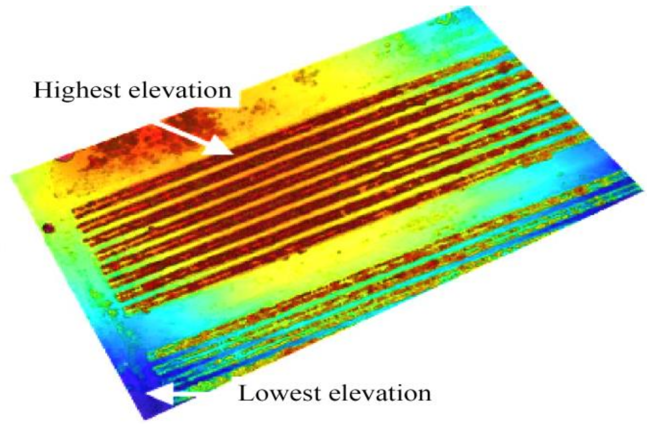
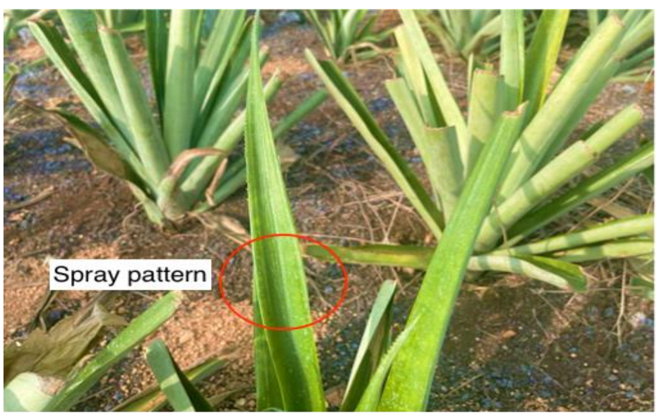
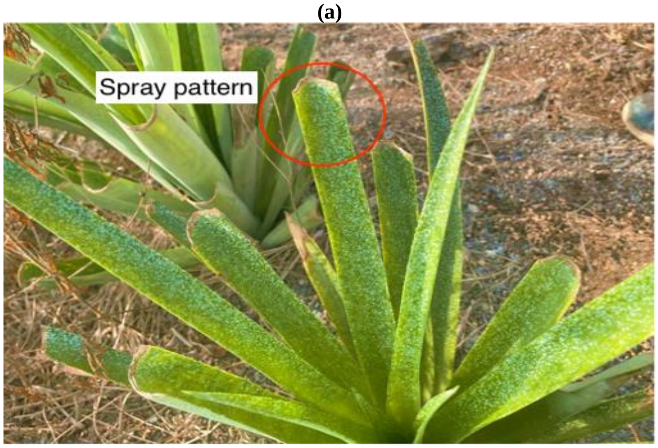


Fig. 4 Mapping data with elevation

With the 3 m/s flight speed, only a quarter acre test field was covered in fertilising, requiring an extra pass compared to the 3 m/s for herbicide, which was completed in two passes. The finding is significant due to the drone's ability to complete the quarter acre with a single battery run instead of half (herbicide). This is because the fertilising spraying rate was 8 L/min and 4 L/min for herbicide. Although similar in altitude, payload, and speed. Fertiliser spraying required double the operation requirements of the herbicide spray to obtain the desired spray quality and prevent nozzle clogging due to the mixtures used.



(a)



(b)

(c)

Fig. 5 Drone spray pattern at 2 m height with (a) 4 m/s, (b) 3 m/s, (c) 2 m/s flight speed

Fig. 6 Clogged nozzle from fertiliser spraying

5. Results and Discussions

Summarising the herbicide field test findings, the farmers were content with a spray rate of 4 L/min at 2 m with a flight speed of 3 m/s and a 06 hollow cone nozzle. As for fertilising, the flight speed and altitude remained the same at 2 m and 3 m/s, but the spray rate was doubled to 8 L/m and a coarse nozzle of 10 flat sprays with a removed filter (to mitigate clogging). Analysing the farmer practice in calculation from Table 7 and Figure 7 using 16 L in 3 min for the herbicide spray at 50% flow rate resulted in a 4 L/min spray rate and 8 L/min for the fertilising spray at 100% flow rate. As for the spray width, the calculation is as follows, derived from Figure 8(a):

$$
\begin{aligned}
spray\ width\ (m) &= 2h \tan\theta\ ;\ h\ is\ spray\ height \\
&= 2 * 2 \tan 40^o\ (herbicide) \\
&= 3.3564\ m \\
&= 2 * 2 \tan 55^o\ \ (fertilizing) \\
&= 5.7126\ m
\end{aligned}
$$

The boom width establishes the maximum width under the spray, 2.55 m. The length under the boom is multiplied by 2 for both sides of the boom, and the angle is half of the spray angle.

For the hollow cone, it is 40° and 55° for the flat spray nozzle, Table 8. A total spray width of 5.9064 m for the hollow cone and 8.2626 m for the flat spray. A 70.24% and 24.99% spray overlap. Derived from Figure 8(b) in the equation below:

$$
\begin{aligned}
&total\ spray\ width\ (m)\\
&\quad = (2 * boom\ width) + spray\ width\\
&\quad = 5.9064\ m\ (hollow\ cone)\\
&\quad = 8.2626\ m\ (flat\ spray)
\end{aligned}
$$

$$
\begin{aligned}
&\%\ overlap\ (fertilizing)\\
&\quad = \frac{spray\ width - spray\ gap}{spray\ width} * 100\%\\
&\quad = \frac{2.8563 - 0.85}{2.8563} * 100 = 70.24\%
\end{aligned}
$$

$$
\begin{aligned}
&overlap\ area\ (m^2)\\
&\quad = R^2 - arccos\left(1 - \frac{h}{R}\right)\\
&\quad - x\sqrt{R^2 - x^2}; x\ is\ (R - h)\\
&\quad = 1.6782^2\ arccos\left(1 - \frac{1}{1.6782}\right)\\
&\quad - 0.6782\sqrt{1.6782^2 - 0.6782^2}\\
&\quad = 2.2112\ m^2
\end{aligned}
$$

$$
\begin{aligned}
total\ overlap &= 2 * overlap\ area = 2 * 2.2112\\
&= 4.4224\ m^2
\end{aligned}
$$

$$
total\ area = 2 * \pi * \ 1.6782^2 = 17.722\ m^2
$$

$$
\begin{aligned}
\%\ overlap\ (herbicide) &= \frac{total\ overlap}{total\ area} * 100\\
&= \frac{4.4224}{17.6957} * 100 = 24.99\%
\end{aligned}
$$

Calculating the coverage is essential in evaluating the effectiveness of the drone as a crop-spraying drone and getting the distance from the flight time and flight speed. A 150 m plot length from the site enables the number of passes to be obtained. As noted in the flow rate and flight time, the number of passes corresponds and is halved for fertilising.

$$
\begin{aligned}
&distance\ travelled\ (m)\\
&\quad = flight\ speed * time\ of\ flight * 60\\
&\quad = 2 * 1.5 * 60 = 180\ m\ (360\ m\ @\ 3min)\\
&\quad = 270\ m\ (540\ m); @\ 3\ m/s\\
&\quad = 360\ m\ (720\ m); @\ 4\ m/s
\end{aligned}
$$

$$
passes = \frac{distance\ travelled}{length\ of\ plot}
$$

$$
= \frac{270}{150} = 1.8\ passes\ (fertilizing)
$$

$$
= \frac{540}{150} = 3.6\ passes\ (herbicide)
$$

$$
\begin{aligned}
area\ covered &= passes * total\ spray\ width\\
&* length\ of\ plot
\end{aligned}
$$

$$
\begin{aligned}
&= 3.6 * 5.9064 * 150 = 3189.456\ m^2\\
&\approx 0.7881\ acre\ (herbicide)\\
&\approx 0.314\ hectare\\
&= 1.8 * 8.2626 * 150 = 2230.902\ m^2\\
&\approx 0.5512\ acre\ (fertilizing)\\
&\approx 0.223\ hectare
\end{aligned}
$$

Table 7. Drone spraying case study data table

Specification	Value
Spraying Rate	8 L/min
Max Pressure	1.2 Mpa
Tank Capacity	16 L
Spray Gap	0.85 m
Boom width	2.55 m
Flight time (herbicide)	3 min (at 50% flow)
Flight time (fertilising)	1.5 min (at 100% flow)

Table 8. Drone spraying datasheet table

Specification	Hollow cone (Herbicide)	Flat spray (Fertilizer)
Spray angle	80°	110°
Pressure range (recommended)	2-20 Bar (0.48-1.52 L/min)	2-5 Bar (0.48-0.76 L/min)
Spray gap (recommended)	0.25 m	0.5 m
Spray height (from top of the crop)	0.65 cm	0.75 cm

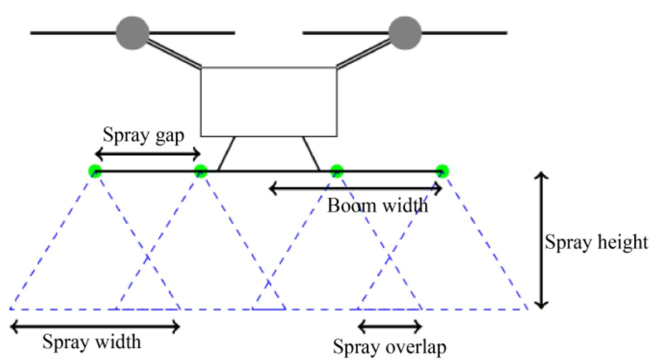
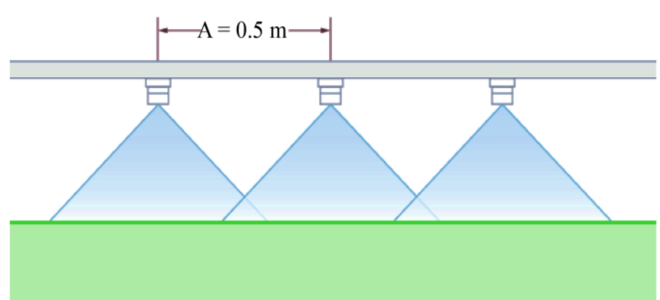
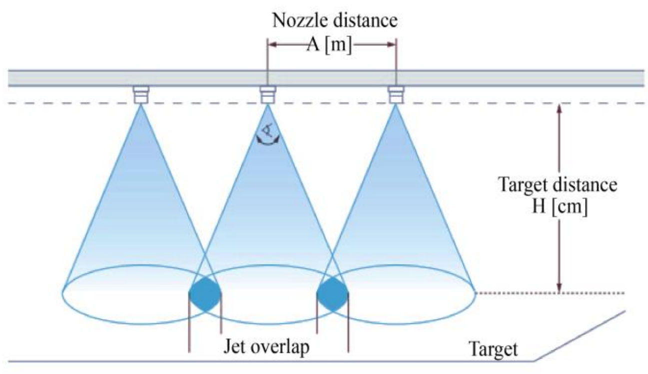


Fig. 7 Drone spray configuration, A-boom length, B-spray gap, C-drone height, D-spray width, E-spray overlap



(a)



(b)

Fig. 8 Spray overlap (a) Flat spray (b) Hollow cone

There is a difference between the farmer's practice and the datasheet from the sprayer nozzle manufacturer. The paper implemented a wider spray gap due to the higher spray height. The paper is not focused on the optimum spray gap and height but on the product application that satisfies the needs of the farmers. Hence, it has a maximum coverage of 0.7881 acres (herbicide) and 0.5512 acres (fertilising) from a single flight, allowing it to fly twice with a single battery covering 1.576 acres with 32 L of herbicide in 6 minutes.

However, due to the high flow rate, fertiliser requires 32 L for the 6 minutes, with 1.1024 acres per battery; this is due to the return trip for the refill consuming the other half of the battery. Recalling an interview with the farmer, the fertilising was done manually. It consumed 200 L of water per acre and 1.5 hours of labour by two men (due to traversing the crop being difficult and the product having to be diluted to allow the worker to apply it to the crops).

With two battery packs and 4 flights, the drone platform can cover the acre in 14 minutes with 64 L of water (adjusted to overlaps and round trip inefficiencies). There was a 68% reduction in water consumption and an 83.3% drop in the manpower requirement.

6. Conclusion and Recommendation

Concluding the study, the pineapple agriculture sector in Malaysia is expected to grow in the coming years. Leveraging drones and automation to reduce operation costs and increase productivity by 83.3% in manpower for herbicide and 41.6% for fertilising is seen as an advantage to the industry. The study also noted a flight speed of 3 m/s and an altitude of 3 m for both fertilising at a 100% flow rate of 8 L/min and herbicide spray at a 50% flow rate of 4 L/min was to the approval of the farming practice based on the feedback and guideline by MPIB.Additional benefits include reducing water consumption for spraying by 68% for herbicides and 34% for fertiliser, which will aid in water scarcity and conservation issues. Using drone automation reduces the possibility of runoffs in overusing products in the field with accurate control and distribution. Compared to other spraying literature, the paper provided insight into resource utilisation and the practical configuration for spraying instead of an optimised theoretical and behavioural study using direct farmer feedback.

6.1. Recommendation

The 70% overlap in the spray is the least desired result in this study, but the farmers were content with the distribution of the product in the field. However, this will require further testing to determine the proper configuration of the spray gap relative to performance and altitude to avoid over-application of the product due to the overlap.

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