

SPRAY COVERAGE AND EFFECTIVENESS OF UNMANNED AERIAL VEHICLE POINT-TO-POINT SPRAYING TECHNOLOGY FOR THE CONTROL OF *Oryctes rhinoceros* IN IMMATURE OIL PALM

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ABSTRACT

The study aimed to elucidate the characteristics of spray coverage and the effect of spraying in controlling *Oryctes rhinoceros* beetle (ORB) in immature oil palm using an unmanned aerial vehicle point-to-point (UAVPTP) sprayer. The UAVPTP sprayer was compared to the semi-mechanised FM ORYCT sprayer and the INTER knapsack sprayer. The water-sensitive paper was used as a sampler to determine spray coverage and droplet density and was statistically analysed. Spray volume per palm was determined via a special calibration method, and fresh damage incidences of ORB attack before and after treatment of cypermethrin insecticide using the UAVPTP were conducted to determine the effectiveness of the treatments. The results showed that the spray coverage of UAVPTP at the targeted spears and first spiral of fronds reached a satisfactory level of above 80%. No significant differences were observed in the fresh damage of ORB ($F_{5,6} = 0.85$, $p > 0.05$ (1st-year-flat); $F_{5,6} = 2.34$, $p > 0.05$ (1st-yr-terrace); $F_{5,6} = 0.67$, $p > 0.05$ (2nd-yr-flat); $F_{5,6} = 1.92$, $p > 0.05$ (2nd-yr-terrace)) upon treatments of cypermethrin between the UAVPTP sprayer, FM ORYCT semi-mechanised sprayer or INTER knapsack sprayer after six rounds of spraying treatment at all types of field terrains. The study results provide the theoretical basis and technical support for decision-making in using the UAVPTP sprayer in immature oil palms.

Keywords: cypermethrin, *Oryctes rhinoceros*, point-to-point spraying, spray coverage, unmanned aerial vehicle (UAV).

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INTRODUCTION

Oryctes rhinoceros beetle (ORB) is one of the major pests that attack immature oil palms. Adult ORB feeds on the cabbage and spear parts of the palms, causing damage to the growing points (Ho, 2010). Losses due to ORB have been reported to reach 53% in the first year of harvesting (Chung et al., 1999). In addition, Chung et al. (1999) also discovered that the beetle damage could cause an average crop loss of 40%–92% during the first year of harvesting. Adult ORBs can live for about 6–9 months. They

feed on the immature palm tissue for up to 4 days before they move to another palm. This process leads to severe crop loss (Desmier & Kang, 2001). Due to beetle attacks, a reduction of >15% in canopy size had also been observed (Samsudin et al., 1993), which often result in reduced photosynthetic activity, delayed plant maturity, smaller fruit bunch size and an approximately 25% crop loss (Liau & Ahmad, 1991).

To effectively control ORB, one of the common treatments is via spraying using cypermethrin insecticide at the spear region and bole of the palm with a spray volume of 100–200 mL/palm. The targeted spear and the base of the first spiral of younger fronds must be wetted to ensure that effective control of ORB is achieved. Spraying is conducted at 14-day intervals as a regular treatment to prevent severe damage and provide

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good protection for palms without delaying the immature period (Ho, 2010). Although there are other methods, e.g., cultural control via constructing the close ended conservation trenches (CECT), the establishment of legume cover crops (LCC) and the biological control methods using *Metarhizium* bioinsecticides, chemical control is still required in areas where ORB infestation is significant. The spraying of cypermethrin insecticide is currently being practised in major plantation estates at a dosage of 0.1% active ingredient (a.i.) concentration with the spray volume of between 100–200 mL to the spear, new fronds and spear bases when damage has been detected. Cypermethrin insecticide used for the control of ORB is non-systemic; it only remains on the exterior of the plant and must be in contact and absorbed through the body of the insect, and may also act as a poison in the insect's stomach. It attacks the nervous system and interacts with the sodium channel in the insects, thus affecting neuron function (Macbean, 2012). Currently, spraying is done manually using conventional knapsack sprayers (CKS) or semi-mechanised tractor-drawn power sprayers. The current method of spraying using CKS is highly labourious, with productivity between 2–4 ha/man-day depending on the field terrain. Lower productivity is observed in fields with terraces. Therefore, there is a need to seek alternatives to replace this laborious method, and the use of precision agriculture using an unmanned aerial vehicle via point-to-point (UAVPTP) autonomous sprayer could be a good technological solution to this problem.

Precision agriculture (PA) technology that embodies the advancement in crop yield optimisation and managerial decision-making through cutting-edge sensor technology and analytical tools is capable of elevating production rates, streamlining labour and optimising fertiliser, irrigation and pest management. PA presents a solution to this issue through the precise monitoring and forecasting of pests, which improves productivity and guarantees environmental sustainability (Kanwal et al., 2022; Mulla, 2013). Kanwal et al. (2022) postulated that various PA technologies have enabled farmers to monitor and manage pests, including remote sensing, the Internet of Things (IoT), geographical information systems, and artificial intelligence. In the aerial field of precision agriculture, unmanned aerial vehicles (UAV) operation stands out among automation machinery due to its high flexibility, ease of control, high adaptability to complex terrain and high efficiency (Liu & Li, 2023). Hilz and Vermeer (2013) reported that UAV have emerged as capable plant protectors. It has the advantages of high operational efficiency, high speed and low drift, but it is also affected by environmental factors; UAV spraying often produces droplet drift. The control effects of UAV spraying on cotton aphids

and spider mites were 63.7% and 61.3%, respectively (Lou et al., 2018). Drones, when equipped with precision techniques and variable-rate nozzles, minimise the use of pesticides, resulting in cost savings on pesticide materials. This makes drones a well-suited tool for PA. Moreover, drones excel in situations involving hazardous chemicals like pesticides. By flying closely to the crop canopy, they ensure that pesticides directly reach the leaves, with minimal runoff to the soil. Drones also target only pest-affected areas, avoiding wasteful pesticide application across the entire field, making them highly efficient (Krishna, 2017).

An innovation of spraying using an UAVPTP spraying method on top of the palm canopy has recently been introduced to replace the existing spraying method. One of the inventions is the UAVPTP sprayer under the trade name of ORYCTES, produced by a Malaysian company, Aonic Sdn. Bhd. (Aonic) (formerly known as Poladrone Solutions Sdn. Bhd.) (Figure 1). The sprayer consists of an airframe with 6 propeller blades and a propulsion system, 16 L tanks with a spraying pump fitted with a TG-8 full cone nozzle and powered by a 12S lithium polymer battery. It is equipped with collision avoidance radar and an altimeter radar system to detect and conduct point-to-point spraying on the palms (Aonic, 2021). ORYCTES has been claimed to be capable of conducting point-to-point spraying over the top of the palm canopy, delivering precise dosage, flying autonomously and being able to spray palms in terraced and hilly areas. SD Guthrie Research Sdn. Bhd., under the R&D Crop Protection Section, Plantation Research & Advisory Department, collaborated with Aonic with the objectives to develop, optimise and study the UAVPTP sprayer on its spray coverage and spray effectiveness. It was hypothesised that the UAVPTP would be able to provide satisfactory spray coverage on the targeted spear base region of the immature palms and be able to effectively control the ORB in the immature palms. This article provides a detailed report and discussion of the study.

MATERIALS AND METHODS

Before the commencement of the research, R&D Crop Protection, SD Guthrie Research Sdn. Bhd., had set a list of parameters for the UAVPTP evaluation, which is listed in Table 1.

Trial Location and Treatment List

A total of four trials were conducted for four types of immature palm fields located in SD Guthrie Berhad's oil palm plantation in Johor, Malaysia, based on the following (Table 2).



Figure 1. ORYCTES unmanned aerial vehicle point-to-point (UAVPTP) sprayer.

TABLE 1. PARAMETER REQUIREMENTS FOR SPRAYING ACTIVITY FOR *Oryctes rhinoceros* BEETLE (ORB) CONTROL IN IMMATURE OIL PALM

Parameter requirements	Description
Targeted spray area	Spear, spear base, and the first spiral of fronds
Spray coverage	>80% at the spear base
Spray droplet density	>70 droplets/cm ²
Spray volume	Palm age between 1–2 yr: 100–200 mL/palm Palm age between 2–4 yr: 200–400 mL/palm
UAVPTP sprayer movement	Point-to-point spraying on top of the palm canopy
UAVPTP automation	To spray autonomously
Bio efficacy	ORB fresh damage incidences to reach below 5% after treatments

Note: UAVPTP - unmanned aerial vehicle point-to-point.

TABLE 2. TRIAL LIST AND TYPE OF FIELD

Trial	Field	Palm age at first round of treatment	Terrain
A	1st yr immature planting	6 months (1st yr)	Flat
B	1st yr immature planting	6 months (1st yr)	Terrace
C	2nd yr immature planting	18 months (2nd yr)	Flat
D	2nd yr immature planting	18 months (2nd yr)	Terrace

Note: yr - year.

All trials were conducted with the treatment list as shown in Table 3.

The FM ORYCT semi-mechanised sprayer was invented by a plantation estate in SD Guthrie Berhad in the Southern Region, Johor, Malaysia. FM ORYCT consists of a semi-mechanised tractor that was modified and installed with a fibreglass tank, water pump, telescopic lance and fitted with a hollow cone nozzle. GOIZPER Group company from Spain, produces the INTER knapsack sprayer, which is currently being sold in Malaysia. The INTER knapsack sprayer has a tank capacity of 16 L, and a long lance fitted with very low volume (VLV) hollow cone nozzles. The sprayer is capable of operating between 1.5–3.0 bar operating pressure. This is the common knapsack sprayer used in many plantations for ORB control (Goizper Group, 2023).

Spraying Methodology

The spraying methodology for the UAVPTP is based on the use of a Global Navigation Satellite System (GNSS) and Real-Time Kinematic (RTK) System that is elaborated as follows:

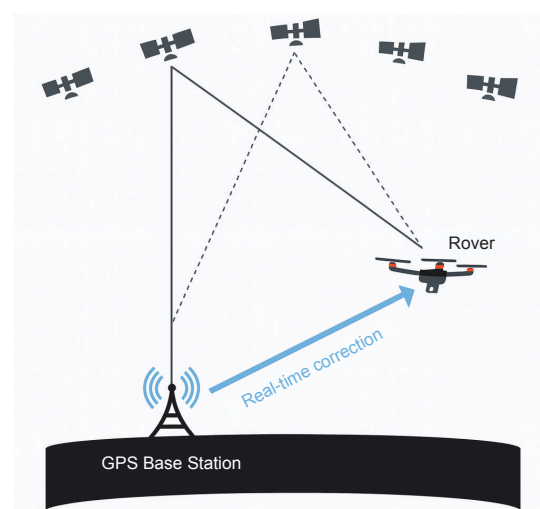
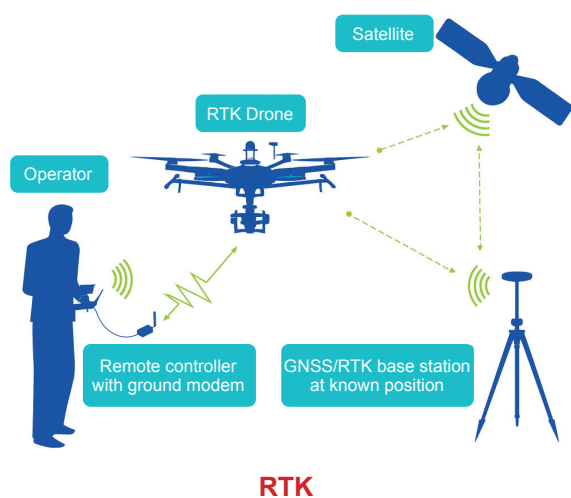
Global Navigation Satellite System (GNSS) and Real-Time Kinetic (RTK) System. GNSS is a satellite navigation system that uses small satellites to pinpoint the geographic location of a user's receiver on Earth. The GNSS use a constellation of satellites and is based on the concept of trilateration (determining a position by knowing your distance from three known points). The UAVPTP sprayer uses the RTK system, which is a GNSS technique that can improve the accuracy of GNSS positioning up to 1–2 cm level. RTK-enabled drones can track their geolocation accurately (Figure 2).

For the UAVPTP sprayer, a pre-treatment flight path was created via digital mapping of the field, and each palm was geotagged at the centre of the canopy to ensure precise point-to-point spraying at the spear and first spiral of the frond conducted. The UAVPTP sprayer was calibrated to provide a similar spray volume application rate per palm at 150 mL. This was implemented by determining the nozzle's flow rate and setting the timing to

TABLE 3. TREATMENT LIST

Trial	Treatment Spray coverage studies (palm)	Replicate	Number of palms per replicate (Experimental unit)	Treatment Fresh damage studies (palm)	Replicate	Minimum number of palms per replicate (Experimental unit)
A	T1: UAV Point-to-Point Sprayer – ORYCTES (UAVPTP) T2: FM ORYCT – Semi- mechanised sprayer T3: INTER knapsack sprayer	3	1	T1: UAV Point-to-Point Sprayer – ORYCTES (UAVPTP) T2: FM ORYCT – Semi-mechanised sprayer T3: INTER knapsack sprayer T4: Untreated control	3	73
B	T1: UAV Point-to-Point Sprayer – ORYCTES (UAVPTP) T2: FM ORYCT – Semi- mechanised sprayer T3: INTER knapsack sprayer	3	1	T1: UAV Point-to-Point Sprayer – ORYCTES (UAVPTP) T2: FM ORYCT – Semi-mechanised sprayer T3: INTER knapsack sprayer T4: Untreated control	3	61
C	T1: UAV Point-to-Point Sprayer – ORYCTES (UAVPTP) T2: FM ORYCT – Semi- mechanised sprayer T3: INTER knapsack sprayer	3	1	T1: UAV Point-to-Point Sprayer – ORYCTES (UAVPTP) T2: FM ORYCT – Semi-mechanised sprayer T3: INTER knapsack sprayer T4: Untreated control	3	130
D	T1: UAV Point-to-Point Sprayer – ORYCTES (UAVPTP) T2: FM ORYCT – Semi- mechanised sprayer T3: INTER knapsack sprayer	3	1	T1: UAV Point-to-Point Sprayer – ORYCTES (UAVPTP) T2: FM ORYCT – Semi- mechanised sprayer T3: INTER knapsack sprayer T4: Untreated control	3	58

Note: UAVPTP - unmanned aerial vehicle point-to-point.



Source: Loosli (2020).

Figure 2. Global Navigation Satellite System (GNSS) and Real-Time Kinematic (RTK) system (trilateration concept).

spray per palm on each palm canopy. Spraying treatment was conducted using cypermethrin insecticide at a dosage of 0.1% a.i. with the spray volume of 150 mL, and the spraying time was set at 3 s/palm.

A base point was set at the highest point near the spraying area as a suitable location for the RTK base station. A Phantom 4 RTK drone was deployed to capture high-resolution aerial images with RTK-calibrated geospatial information. The aerial images were uploaded onto a software mapping platform that stitched the images into a cohesive map and generated a high-precision Digital Terrain Model (DTM). The software AI palm identification algorithm was used to pinpoint and tag individual palm crowns in the aerial map, and the GPS information of the detected palms was extracted for UAVPTP sprayer path planning. A path-planning algorithm was used to generate an optimal flight path for the UAVPTP sprayer that covers the plot within the shortest flight time. The generated flight path was visually reviewed in the software and then synced with the UAVPTP sprayer mobile app used to pilot the spraying drone.

During the spraying operation, the UAVPTP RTK base station was set up at the previously established base point, then the UAVPTP was turned on to establish a stable connection with the base station. The cypermethrin liquid insecticides were filled into UAVPTP at 14 L, and the pump system of the drone was checked to ensure smooth liquid flow through the nozzle. A pre-flight checklist (RTK signal strength, radar sensors, battery status, etc.) was run through to ensure the drone was ready for take-off. The pre-planned flight mission was reviewed for the final time on the UAVPTP mobile app, then the drone was launched in automatic mode to perform the pre-planned missions (Figure 3). During a drone flight, the pilot constantly monitored and ensured the drone flew along the correct paths and with a stable RTK connection. The UAVPTP mobile app captured all the data during the spraying for easy reporting (How & Ken, 2020). The temperature recorded was between

29°C–32°C with relative humidity between 65%–72%. The wind speed was recorded at 1–2 m/s, and the flight was set not to operate at 3 m/s and above.

For the INTER Knapsack Sprayer and FM ORYCT (Figure 4), the spraying treatment was conducted using cypermethrin insecticide at a dosage of 0.1% a.i. with the calibrated spray volume of 150 mL/palm. Calibration was conducted similarly to the UAVPTP via the determination of the average flow rate of the nozzles and setting the timing to spray per palm on each palm.

Spray Coverage and Spray Droplet Density Assessment

As displayed in Table 3, spray coverage studies related to all the machinery treatments (T1: UAV Point-to-Point Sprayer – ORYCTES (UAVPTP), T2: FM ORYCT – Semi-mechanised sprayer and T3: INTER knapsack sprayer) were conducted using water-sensitive paper (WSP) on three palms that represent three replicates (one palm per replicate) for the 1st, 2nd and 3rd rounds of spraying. The WSP was placed on the palm spears and at the base of the first spiral of the frond (6 points) (spear region). In addition, WSPs were placed on the 6 points at the lower, middle and upper fronds in the palm canopy surrounding the spears to study any drift of the spray droplets. As mentioned earlier, during the trial, the temperature recorded was between 29°C–32°C with relative humidity between 65%–72%. The wind speed was recorded at 1–2 m/s and flight was set not to operate at 3 m/s and above. The scoring of spray coverage was recorded based on the scale and weightage in Table 4. The droplet density for each WSP was analysed using the Syngenta Droplet Counting Aid to determine the number of droplets/cm².

Fresh Damage Assessment

Before the trial, the palms in all the fields were continuously treated with cypermethrin by the plantation estate every 14 days, and sprayings were

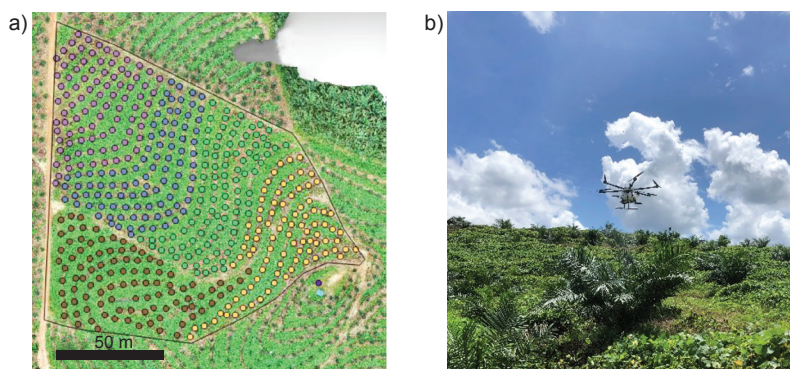


Figure 3. (a) Layout of mapping, flight path and geotagging of palms for the unmanned aerial vehicle point-to-point (UAVPTP) and (b) unmanned aerial vehicle point-to-point (UAVPTP) spraying on immature palms.



FM ORYCT semi-mechanised sprayer.



INTER knapsack sprayer.

Figure 4. FM ORYCT semi-mechanised sprayer and INTER knapsack sprayer.

TABLE 4. VISUAL SCORE RATING (VSR) OF WATER-SENSITIVE PAPER (WSP), SCORE WEIGHTAGE AND TOTAL SPRAY COVERAGE CALCULATION

Spray coverage description of each WSP	VSR (%)	Location of WSP	Score weightage for ORB control (%)	Calculation of spray coverage for each WSP point	Total spray coverage calculation
Full wetting	100	Spear Base 1 (SB1)	20	$VSR \times 20\% = SCSB1$	Total spray coverage = SCSB1+ SCSB2+ SCSB3+ SCSB4+ SCSM+ SCSE
Droplet covered 80%–99% of WSP	80–99	Spear Base 2 (SB2)	20	$VSR \times 20\% = SCSB2$	
Droplet covered 60%–79% of WSP	60–79	Spear Base 3 (SB3)	20	$VSR \times 20\% = SCSB3$	
Droplet covered 40%–59% of WSP	40–59	Spear Base 4 (SB4)	20	$VSR \times 20\% = SCSB4$	
Droplet covered 20%–39% of WSP	20–39	Spear Middle (SM)	10	$VSR \times 10\% = SCSM$	
Droplet covered 1%–19% of WSP	1–19	Spear End (SE)	10	$VSR \times 10\% = SCSE$	
No droplet detected	0				

Note: ORB - *Oryctes rhinoceros* beetle.

stopped 21 days before the trial. Fresh damage of ORB assessment for all treatments in Trials A, B, C and D was conducted at pre-treatment and every seven days after each spraying treatment round (1st round until 6th round) to determine the spraying effectiveness. Fresh damage of ORB refers to spear snapping due to fresh chewing on the basal end, unopened spear dieback (easily pulled out), distinct chewing marks on the spear and spear cut-off and snapping of newly opened fronds. The assessment was conducted on all the palms in each replicate, and the percentage based on the number of damaged palms divided by the number of total palms in each replicate was reported as the data for fresh damage.

Experimental Design and Statistical Analysis

All the experiments were conducted in a randomized complete block design (RCBD) with three replications. All percentage data were subjected to analysis of variance (ANOVA) using the generalized linear model (GLM) to detect the differences between treatment effects, and means were compared using Tukey's HSD Test.

RESULTS AND DISCUSSION

Spray Coverage and Spray Droplet Density Assessment

Results from the spray coverage are tabulated in Table 5. In the first-year immature palms in flat terrain and the second-year immature palms in terrace terrain, the results showed that at the first to third round of treatment, INTER Knapsack and FM ORYCT showed significantly better spray coverage than the UAVPTP sprayer, this is understandable due to the ability of the workers to spray the whole spear shoot manually. Nevertheless, the results showed that the UAVPTP sprayer reached above 80% satisfactory spray coverage at the targeted area of the spear region for all the field terrains experimented with and for both first-year and second-year immature palms. Since the major targeted area is at the base of the spear region, the results proved that UAVPTP could reach the targeted area on the palms for all the fields, either flat or terraced.

As all the droplets at the spear region showed 100% wetting on the WSP due to the overlapping of spray droplets, the droplet density was declared as

above 70 droplets/cm², which met the requirement set. All the treatments showed 100% wetting of the WSP, especially at the spear base region (Figure 5).

Fresh Damage Assessment

The fresh damage assessment results are tabulated in Table 6. The outcome of the trials showed that UAVPTP showed effective control of ORB in the one-year immature planting in a terrace field (Trial B in Table 6) compared to the untreated control, significantly after 1st round of treatment (A1STRT). These were observed significantly after the first, second, third and fifth rounds of treatment of UAVPTP against the untreated control plots in the 1st Year Immature Palms-Terrace Plot trial. However, during the trial, low pest pressure was observed in the one-year-old immature planting under flat terrain (Trial A) and two-year-old immature planting under both flat and terrace terrain (Trials A, C and D in Table 6)

after the A1STRT. No significant differences in the level of control between the UAVPTP sprayer, FM ORYCT and the INTER knapsack sprayer for all the fields experimented after the 6th round of treatment. It was suspected that continuous cypermethrin treatment surrounding the untreated control plots had reduced the pest pressure in the fields.

Discussion

From the spray coverage, droplet density and bioefficacy results, UAVPTP showed good capability to replace the current spraying method of using the INTER knapsack sprayer as well as the FM ORYCT semi-mechanised sprayer for ORB control in immature palms. The geotagging and geopositioning via RTK-GNSS were accurate and aligned with the study conducted by Pérez-Ruiz et al. (2015), which reported that autonomous tractor systems showed good feasibility for extreme accuracy requirements.

TABLE 5. SPRAY COVERAGE (%) OF UNMANNED AERIAL VEHICLE POINT-TO-POINT (UAVPTP) SPRAYER VS. OTHER SPRAYERS

Palm age/ Terrain	Treatment	A1STRT	A2NDRT	A3RDRT
1st yr immature palms/Flat (Trial A)	UAVPTP sprayer	85.00 c ^z	81.67 b	85.00 b
	FM ORYCT semi-mech sprayer	90.00 b	93.33 a	93.33 a
	INTER knapsack sprayer	95.00 a	96.67 a	96.67 a
1st yr immature palms/Terrace (Trial B)	UAVPTP sprayer	83.33 c ^z	83.33 a	83.33 a
	FM ORYCT semi-mech sprayer	90.00 b	88.33 a	88.33 a
	INTER knapsack sprayer	95.00 a	93.33 a	91.67 a
2nd yr immature palms/Flat (Trial C)	UAVPTP sprayer	86.67 a ^z	83.33 b	83.33 a
	FM ORYCT semi-mech sprayer	93.33 a	91.67 ab	93.33 a
	INTER knapsack sprayer	95.00 a	95.00 a	93.33 a
2nd yr immature palms/Terrace (Trial D)	UAVPTP sprayer	81.67 b ^z	83.33 b	83.33 b
	FM ORYCT semi-mech sprayer	91.67 a	93.33 a	93.33 a
	INTER knapsack sprayer	93.33 a	95.00 a	95.00 a

Note: A1STRT - At 1st round of treatment; A2NDRT - At 2nd round of treatment; A3RDRT - At 3rd round of treatment. ^zMeans within the same column followed by the same letter are not significantly different at *P* - 0.05 based on Tukey HSD for each of the trials. All data were transformed into arcsine for statistical analysis, and the original data were used for presentation.

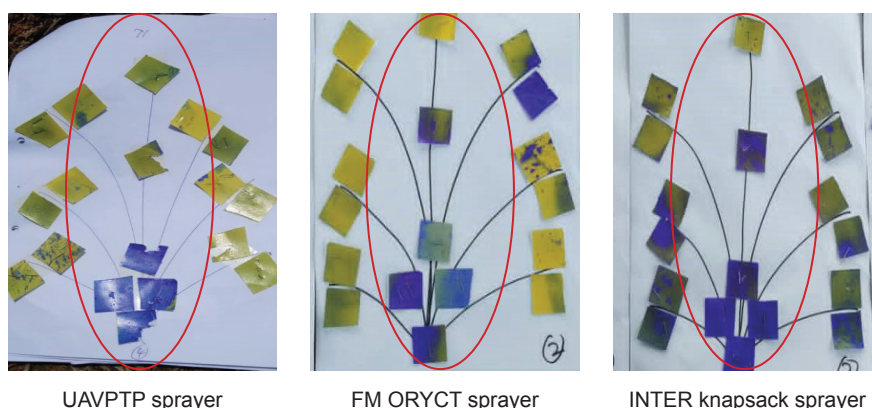


Figure 5. Spray coverage evaluation for all the sprayers.

TABLE 6. FRESH DAMAGE OF *Oryctes rhinoceros* BEETLE (ORB) ON IMMATURE PALMS AFTER TREATMENT OF CYPERMETHRIN

Palm age/Terrain	Treatment	Pre-treatment	A1STRT	A2NDRT	A3RDRT	A4THRT	A5THRT	A6THRT					
1st yr immature palms/ Flat (Trial A)	UAVPTP sprayer	0.00	a ^z	0.34	b	0.00	b	0.91	a	0.28	a	0.23	a
	FM ORYCT sprayer	0.00	a	0.65	a	0.31	a	0.39	a	0.97	a	0.26	a
	INTER knapsack sprayer	0.00	a	0.01	c	0.31	a	0.14	b	0.00	a	0.00	a
	Untreated control	0.00	a	0.46	ab	0.01	b	0.10	b	0.35	a	0.12	a
1st yr immature palms/ Terrace (Trial B)	UAVPTP sprayer	0.30	a ^z	0.72	b	0.00	c	0.41	b	0.52	a	0.00	a
	FM ORYCT sprayer	0.34	a	0.12	b	1.03	a	0.26	b	0.43	a	0.26	a
	INTER knapsack sprayer	0.00	a	0.24	b	0.34	bc	0.20	b	0.61	a	0.00	a
	Untreated control	0.35	a	5.96	a	0.65	b	0.95	a	0.95	a	0.32	a
2nd yr immature palms/ Flat (Trial C)	UAVPTP sprayer	0.35	a ^z	1.19	b	0.38	a	0.38	b	1.13	b	0.26	a
	FM ORYCT sprayer	0.34	a	0.96	b	0.37	a	5.99	a	6.18	a	0.19	a
	INTER knapsack sprayer	0.36	a	2.05	a	0.36	a	0.40	b	1.26	b	0.18	a
	Untreated control	0.26	a	1.20	b	0.26	a	1.82	b	0.09	b	0.26	a
2nd yr immature palms/ Terrace (Trial D)	UAVPTP sprayer	0.00	a ^z	1.92	ab	0.65	b	0.00	b	1.15	a	0.65	a
	FM ORYCT sprayer	0.00	a	1.12	b	1.15	b	2.43	a	1.50	a	0.19	a
	INTER knapsack sprayer	0.20	a	2.74	a	2.23	a	0.18	b	0.90	a	0.54	a
	Untreated control	0.13	a	1.44	b	1.57	ab	2.49	a	1.05	a	0.59	a

Note: A1STRT - 7 days after 1st round of treatment; A2NDRT - 7 days after 2nd round of treatment; A3RDRT - 7 days after 3rd round of treatment; A4THRT - 7 days after 4th round of treatment; A5THRT - 7 days after 5th round of treatment; A6THRT - 7 days after 6th round of treatment. ^zMeans within the same column followed by the same letter for each of the trials are not significantly different at $P = 0.05$ based on Tukey HSD. All data were transformed into arcsine for statistical analysis, and the original data were used for presentation.

The spray effectiveness of UAVPTP was satisfactory, even though some of the fields showed low pest pressure. The low pest pressure was observed in the untreated plots and was expected to occur due to the earlier continuous treatment of the plots before the trials. However, the UAVPTP showed the most significant control compared to the untreated control after the first round of treatment in the first-year immature palms with terrace terrain field (Trial B) and with no significant difference with FM ORYCT and INTER knapsack sprayer.

The spray coverage results were the most important finding in these studies, as UAVPTP spraying had reached the targeted spear base and the first spiral of fronds equally as the manual INTER knapsack sprayer and the mechanical FM ORYCT sprayer, as required and reported by Ho (2010). This has proven that UAVPTP could replace spraying using an INTER knapsack sprayer or the FM ORYCT mechanised sprayer. Table 7 summarises the UAVPTP results that meet the parameter requirements set in Table 1.

The utilisation of UAVPTP demonstrated the capability to apply insecticides with precision, aligning with the principles of integrated pest management (IPM) to minimise insecticide usage (Barzman et al., 2015). The technology's efficiency, as corroborated by Krishna (2017), includes the ability to achieve accurate dosing and precise targeting of crop areas, thereby reducing insecticide drift and minimising losses. Furthermore, UAVPTP facilitates unmanned spraying over extensive areas, decreasing reliance on human labour for large-scale applications. This advancement offers potential cost reductions in workforce recruitment for plantation estates. These findings represent pioneering data that will serve as a reference for future unmanned application technologies in oil palm cultivation.

With the acute shortage of workers due to the restriction on importation of foreign workers caused by closed borders during the COVID-19 pandemic, the UAVPTP spraying method will be the best alternative to solve the ORB infestation issues in the plantation. However, additional requirements for obtaining a license to fly, meeting the safety requirements as well and higher costs will be the main obstacles to overcome in the use of the UAVPTP sprayer.

CONCLUSION

The UAVPTP sprayer achieved satisfactory spray coverage on the targeted area of the spear region in immature oil palm for the control of ORB. The UAVPTP showed effective control of ORB with no significant differences with the FM ORYCT semi-mechanised sprayer and INTER knapsack sprayer at the end of the trial, at first-year and second-year immature oil palm on both flat and terrace terrain fields. UAVPTP met all the requirements set for successful spraying activity in controlling ORB in immature palms.

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TABLE 7. SUMMARY OF UAVPTP ACHIEVEMENT RESULTS ON THE PARAMETER REQUIREMENT FOR THE SPRAYING TREATMENT OF IMMATURE PALMS FOR THE CONTROL OF *Oryctes rhinoceros* BEETLE (ORB)

Parameters	Results	Conclusion
Targeted spray area	Spray droplets had reached the targeted spear, spear base and the first spiral of the frond region.	Meets the requirement
Spray coverage	Spray coverage: >80%.	Meets the requirement
Spray droplet density	The targeted area was fully wetted; therefore, it reached a droplet density above 70 droplets/cm ² .	Meets the requirement
Spray volume	Reached the targeted spray volume as follows: Palm age between 1–2 yr: Spray volume at 150 mL was sufficient to reach the targeted area (within 100–200 mL/palm target).	Meets the requirement
UAVPTP sprayer movement	Able to execute point-to-point spraying on top of the palm canopy.	Meets the requirement
UAVPTP automation	Able to spray autonomously.	Meets the requirement
Bio-efficacy (effectiveness of the pesticides in controlling the target pest)	Results – Equally effective with FM ORYCT semi-mechanised sprayer and INTER knapsack sprayer (reached below 5% after treatments).	Meets the requirement

Note: UAVPTP - unmanned aerial vehicle point-to-point.

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