Aerial spraying application of multi-rotor unmanned aerial vehicle on areca trees

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Abstract: In order to illustrate the effects of droplet deposition on the canopy and the stem of the areca nut sprayed by the multi-rotor Unmanned Aerial Vehicle (UAV), for providing the operation parameter basis for the application of aerial spray in Hainan Province. The effects of MG-1p multi-rotor UAV on different leaf area index (LAI) areca under different operation heights and nozzle types were mainly studied. Eight treatments were carried out in the experiment. Instead of pesticides, seduction red stain agent was selected and prepared into an aqueous solution with a mass fraction of 5‰, with a quantity of 75 L/ha and a flight speed of about 1.3 m/s. The droplets were collected on coated paper and analyzed by DepositScan. The canopy droplet deposition ranged from 0.355 to 0.747 $\mu L/cm^2$, and the deposition level was from 47.32% to 99.55%. The stem layer droplet deposition amount was 0.049-0.304 $\mu L/cm^2$, the deposition level was 6.47%-40.51%. The droplet volume medium (DV_{50}) test results showed that, the effect on the stem layer DV_{50} was very significant when only the type of nozzle was changed or all operating parameters were changed, and the DV_{50} range of droplet volume was 240-525 μm. The test results showed that the deposition amount of ground loss droplets was larger with the lower LAI under the same flight altitude and nozzle type, the deposition amount of ground loss droplets was the smallest when the flight altitude was 7 m, and the deposition amount of ground loss droplets was the largest when the operation height was about 13 m, which was about 2.53 times of height of 7 m. The results of the drift region droplets test showed that 90% of the total spray drift volume distance ranged within 4.5-17.40 m. The test results in this study can provide theoretical and data support for multi-rotor UAV of the areca nut aerial spray operation.

Keywords: Multi-rotor unmanned aerial vehicle (UAV), aerial spraying, areca, leaf area index, deposition, drift law
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1 Introduction

Areca catechu L. is native to the tropical pacific, southeast Asia, south Asia and east Africa. It belongs to the perennial evergreen tree of the palm family[1]. It is mainly distributed in India, China, Indonesia and Africa. It has the functions of killing insects, eliminating accumulation, relieving swelling, reducing blood pressure and treating cerebral thrombosis. It ranks the first among China's four major southern medicines (Areca, Alpinia oxyphylla, Amomum longiligulare, Morinda ojj)[2]. According to the Food and Agriculture Organization of the United Nations and the Statistical Yearbook of Hainan[3,4], The global output of areca in 2016 was 1.214,100 tons, Hainan produced 255,114 tons of betel nut in 2017. By 2018, the planting area of Areca in Hainan Island has reached 15.53 thousand-hectare, accounting for 95% of the national planting area, and it is the main economic source for more than 2.3 million farmers in this province[5]. According to statistics, areca has more than 40 kinds of diseases and more than 100 kinds of insect pests. Among the diseases, yellow leaf disease is the most serious and belongs to phloem systemic disease, which can damage leaves and flowers. Bacterial leaf spot, fruit rot and anthracnose mainly damage fruit, leaves and other parts. According to statistics, areca has more than 40 diseases and more than 100 insect pests[6-9]. Among the diseases, yellowing disease is the most serious and belongs to phloem systemic disease, which can harm leaves and flowers. Bacterial leaf spot, fruit rot, anthrax and other major harm fruit, heart leaves and leaves, and other parts.

The height of areca trees in the mature period can reach 10-20 m, In recent years, the height of the new areca species of 7-8 years old can be controlled in 8~9 meters[10]. At present, there are few research data on mechanized application of areca nut in the world. Some scholars have developed an intelligent climbing spraying device that can climb to 30 feet and spray the canopy in a dry environment, but the efficiency of large-scale pest and disease control is low[11]. Areca trees in Hainan island mostly grow in

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hilly areas, during the seedling stage, the hand-held/ backpack sprayer was used for spraying, which have low efficiency, high intensity and potential pesticide poisoning risks for sprayers. When the height of areca trees is above 2 m, it is more difficult to spray pesticides. Due to tree height and terrain restrictions, ground spraying machinery is difficult to operate. Farmers basically do not control the diseases and pests of areca nut trees in high places, which led to the sharp decrease of areca yield.

Agricultural aviation has the advantages of fast, high efficiency, flexible mobility and strong regional adaptability, and can effectively reduce the harm of pesticides to the environment and pesticide applicators[12-18]. The more developed countries of agricultural aviation in the world are the United States and Japan, followed by Russia, Australia, Brazil and South Korea. The operation parameters of plant protection UAV have important influence on droplet deposition, coverage, drift and distribution uniformity. Due to Japan's small arable land and more mountainous areas, it is not suitable for manned fixed-wing aircraft to operate. In 2013, Japan Yamaha Engine Co., Ltd. conducted an investigation on the operational efficiency and the prevention of existing pests and diseases. Taking 1 hm^2 area as an example, it takes 160 minutes for a backpack sprayer, 60 minutes for tractor spraying, and 10 minutes for unmanned helicopter operation. The Japan Agriculture, Forestry and Fisheries Aviation Association has summarized the experience of UAVs in the aspects of flight altitude, swath width, and flight speed[19,20]. Teske et al. have established a droplet trajectory prediction model by studying the effects of aviation altitude, aircraft wake, tip vortex, rotor downwash flow on droplets[21-23]; Hewitt et al. added real-time meteorological conditions and geographic information system into the droplet diffusion model to reduce the drift in non-target areas[24]; Zhang Songchao et al. used computational fluid dynamics software to simulate the droplet movement in the application of the N-3 unmanned helicopter and obtained qualitative results[25]; Wang et al. Studied the effects of UAV flight parameters on the deposition and distribution characteristics of spray droplets, and gave reference opinions for the spray parameters in the field[26], Zhang et al. studied the droplet deposition of 3W-LWS-Q60S UAV on fruit tree canopy under different citrus tree shapes and flight altitude[27]; Qin et al. studied the influence of different flight altitude and swath width of the N-3 UAV on the distribution of canopy droplets in the late growth period of maize[28]; Chen et al. studied the influence of UAV spray parameters and rotor wind field on the distribution of droplet deposition in the rice canopy, and found that the flight altitude and speed had a significant impact on the average droplet deposition[29,30]; Qiu et al. used a two factor and three level test method to study the interaction between the flight altitude, speed and two factors of the UAV, and the effect of droplet deposition concentration and uniformity on the droplet deposition concentration and uniformity, a regression model was established[31]. Xue et al. studied the N-3 unmanned helicopter at a flight altitude of 5 m, a speed of 3 m/s, and a crosswind wind speed of 3 m/s, where 90% of the droplet drift was within 8 m[32]. Wang et al. studied the application of single-rotor UAV in pineapples, and found that the flight altitude and wind speed have a significant impact on the drift distance[33]. Yao et al. Carried out relevant research on the influence of flight speed, altitude and adjuvant on droplet drift and effective swath width in aviation operation[34].

At present, UAV spraying application has made great progress on low crops, areca tree has begun to use UAV for spraying, the actual operation is still in the exploration stage. The application of UAV in areca nut tree has made great progress in pest control. However, due to the regional limitation and the difficulty coefficient of test, there is no report on the UAV spraying test of areca nut. After the UAV type is determined, the droplet deposition and drift are mainly affected by operation parameters and environmental meteorology[35,36]. The authors visited local farmers and plant protection UAV companies, and found that the flight altitude has a great impact on the preliminary test results. The test used the high-precision Beidou positioning system to obtain real-time flight parameters of the UAV and allure red water solution was used to spray instead of traditional pesticides. Considering the arduous task and high degree of difficulty of this test, after discussing with the testers, a more realistic test plan was formulated, which mainly studied the spraying effects of different working heights, sprinkler types and leaf area index on the canopy and trunk, the ground droplets loss and drift. The test can provide data support and operating parameter for UAV applications on areca trees.

2 Materials and methods

2.1 Instruments

The test used the MG-1p multi-rotor plant protection UAV produced by Shenzhen DJI Technology Co., Ltd., as shown in Figure 1, and the main technical parameters and performance of the UAV are shown in Table 1. The test nozzle models are teejet xr110015vs and teejet xr110002vs fan-shaped nozzles. The flight mode was full coverage reciprocating, and the flight spacing was 4 m. The environmental meteorological monitoring used the NK-5500 Kestrel weather meter produced by the US NK company, and the data was collected every 5 s, the data include environment temperature and humidity, wind speed and wind direction. UAV flight track collected by Beidou system (an aerial Beidou positioning UB351 system developed by the South China Agricultural University with the RTK differential positioning function was equipped), The plane accuracy is up to $(10+5\times D\times 10^{-7})$ mm, and the elevation accuracy is up to $(20+1\times D\times 10^{-6})$ mm, where: “D” represents the distance value measured by the system, and the data collection interval was 0.1 s, the system can record the flight trajectory and precise operation time of the UAV[37], The Leaf area index was obtained by the CI-110 plant canopy image analyzer produced by CID in the United States. According to the instructions of the instrument, the bottom of the plant was shot vertically upwards, the instrument was connected to a handheld tablet computer to display the test images in real time.

Table 1 Main parameters and performance indexes of UAV

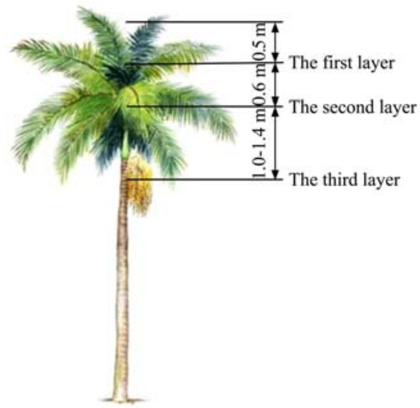
Main parameter	Norms and numerical
Type	MG-1p Multi-rotor electric UAV
Size/mm×mm×mm	1 460×1460×578
Single wing length/mm	619
Symmetrical motor wheelbase/mm	1500
Total Weight/kg	9.8
Maximum effective takeoff weight/kg	24.8
Maximum operating speed/m·s^{-1}	7
Maximum load/L	10
Nozzle quantity	4
Flow rate/L·min^{-1}	1.8-2.4
High precision radar module model	RD2412R
Ranging accuracy/m	0.1
Power Battery	MG-12000P

a.

b.

Figure 1 Physical scene map of single wing unmanned aerial vehicle (UAV) spraying areca test

a.



b.

Figure 2 Sketch map of areca plant and sampling arrangement

2.2 Test method

2.2.1 Test site

The test site was located in the areca demonstration base of the National Center for International Collaboration Research on Precision Agricultural Aviation Pesticides Spraying Technology in Chengmai County, Hainan Province. The height of areca was 4.7-6.28 m, the tree age was 5-6 years, the planting density was 1800 plants/ha, and the row spacing was 2 m×2.5 m, the areca nut was in the flowering stage.

2.2.2 Sampling point layout

Leaf area index (LAI) and vegetation biomass are the characteristic parameters of crop growth status information, which can be used as an important basis for controlling the amount of pesticide spraying. The amount of pesticide spraying is closely related to the severity of pests and diseases. The spraying amount is based on the amount of chemical solution required by the unit volume of crop biomass, not according to the size of unit land area[38]. Under the same spraying amount, the results of droplet deposition on crops with different leaf area indexes at the same spraying rate are different. Two areas of 5 years and 6 years old areca trees were selected for the test. In each area, 5 areca trees with similar LAI (variation coefficient <10%) were randomly selected according to the X type. The average LAI of the first group of areca trees was 0.91, and the average tree height was 4.61 m. The average LAI of the second group of areca trees was 1.65 and the average tree height was 4.96 m. The sampling was divided into three parts, the first part was mainly arranged in the canopy and flower stem layer, as shown in Figure 2, the second part was arranged on the ground to collect the lost droplets; the third part was the droplet sampling in the drift area, the sampling arrangement was shown in Figure 3.

(1) Sampling arrangement of areca nut plant canopy and flower stem layer

The areca tree has an upright stem and clusters of leaves growing on the top of the stem,showing a long and narrow lancet shape. The center is a leaf core that is prone to pests and diseases, the angle between the top leaf and the trunk was small, about 30-50 degrees. The horizontal area in the middle of the canopy was the largest, the angle between the leaves and the trunk was about 60-80 degrees, and the number of leaves was dense, it was a key pest control area. The fruit and flower grow on the trunk, which is called the flower stem layer. According to the growth morphology of areca nut, the sampling was divided into three layers. The first layer was about 0.5 m away from the crown, with a circular arrangement and a diameter of about 1.0-1.2 m. There were 8 sampling points at equal intervals on the circumference and 1 sampling point at the center of the circle, totally 9 sampling points. The second layer was arranged in the middle of the canopy, about 0.6 m away from the first layer, and was circularly arranged with a diameter of about 1.5-1.6 m. The arrangement was the same as that of the first layer, with a total of 9 sampling points. The third layer was arranged in the flower stem layer, the diameter of the trunk was about 0.22 m, the distance from the second layer was about 1.0-1.4 m, and 8 sampling points were arranged at equal intervals on the circumference. The droplet sampling card was white coated paper with a size of 75 mm× 25 mm, the sampling cards of the first and second layers were clamped on the leaves with paper clips at the same growth angle as the leaves. The sampling positions were marked with white filter paper in advance, so as to place and retrieve the sampling cards accurately according to the number. The sampling cards of the third layer were directly nailed to the tree trunk with pushpins. 26 sampling points were arranged for each areca tree, and a total of 260 droplet sampling cards were collected for each flight.

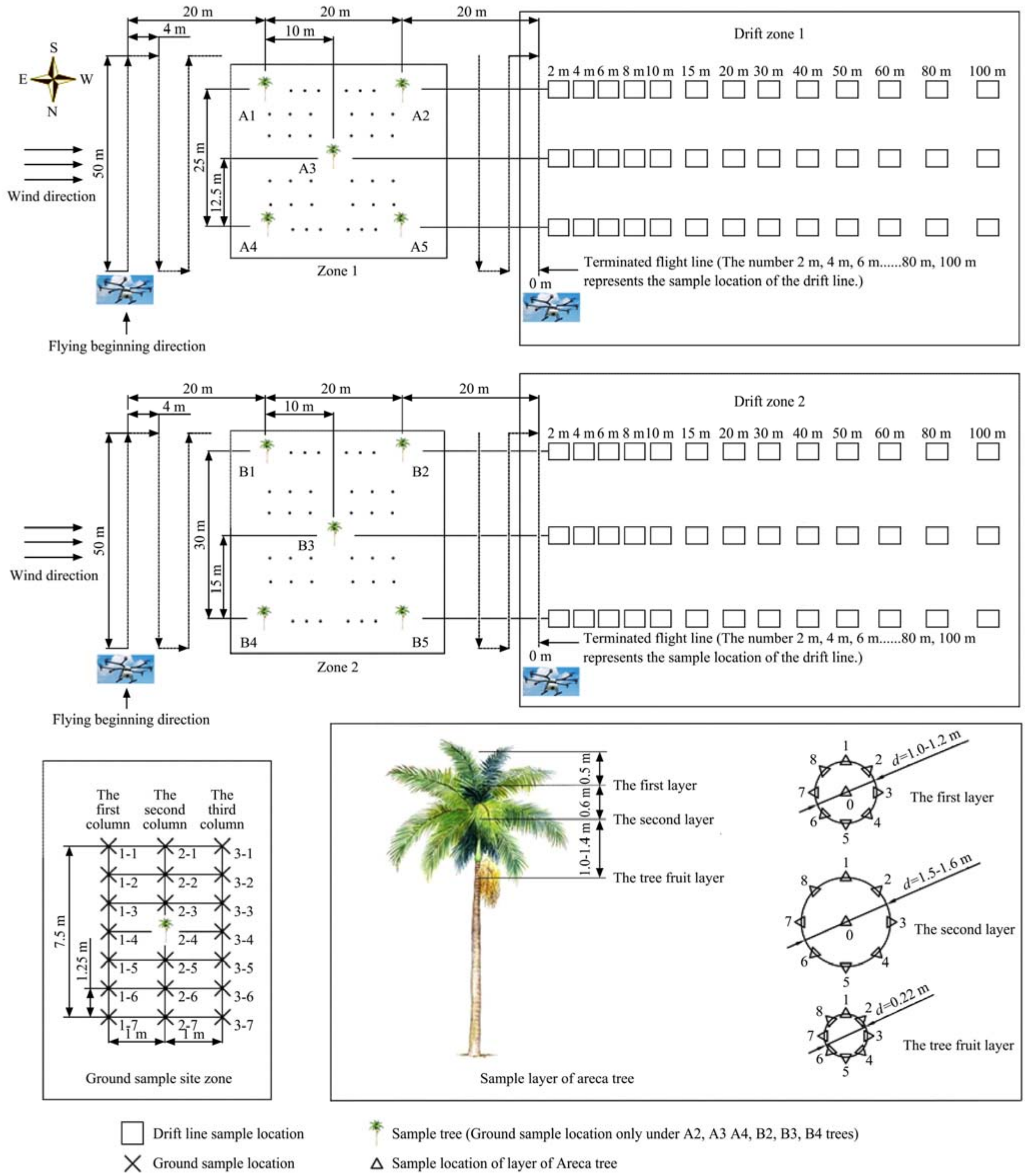


Figure 3 Schematic diagram of test

(2) Non-target loss droplet sampling arrangement on the ground

The ground lost droplets were sampled in the ground area where areca plants were located. 3 ground collection areas were arranged in each sampling area as 3 replicates. Each ground collection area was arranged under three areca trees, including one sampling tree (A2, A3, A4, B2, B3, B4). Each ground collection area was arranged with 3 collection lines, and each collection line was arranged with 7 sampling points, with a total of 21 sampling points. The arrangement and spacing were shown in Figure 3. The layout position comprehensively considers the gap between trees and trees and the interception by canopy. A sharp PVC pipe was inserted into the ground, and a universal clamp was placed about 30 cm away from the ground, and a droplet collection card was placed on the universal clamp. A total of 126 droplet collection cards were collected for each flight.

(3) Sampling arrangement of drift droplets

The drift sampling zone was divided into two parts. The first part was arranged on the extension line of areca nut planting line with an average LAI of 0.91, with three replicates. The second part was arranged on the extension line of areca nut planting line with an average LAI of 1.65. The 2 m position on the right side of the terminating route was set to the right as the drift sampling area, and the terminating route was set to 0 point, A total of 13 sampling points was set at 2 m, 4 m, 6 m, 8 m, 10 m, 15 m, 20 m, 30 m, 40 m, 50 m, 60 m, 80 m and 100 m away from the zero point. And a total of 78 droplet collection cards were recovered for each flight.

2.2.3 Operation parameters and solution configuration

Taking the UAV flight altitude, nozzle type and LAI value as the test processing parameters, the flight speed was set as 1.5 m/s, the spraying rate was 75 L/ha, and the flight altitude was set as 7 m, 10 m and 13 m from the ground. The test needs to be repeated in the same position of the same plant, in order to prevent the repeated spraying of pesticide, the 5 ‰ allure red dye was selected to spray instead of liquid pesticide. The operation mode of UAV was the same as that of field operation, taken off from the top of the first row of areca nut trees on the ground, and the flight spacing was 4 m. The total width of the flight area was 60 m and the flight length was 50 m. In order to ensure the accuracy of droplet collection, the UAV took off and lands 20 m away from the sampling area. The test was divided into 8 treatments, and the test parameters were shown in Table 2. The operating altitude and speed of UAV in the table were processed by the real-time trajectory map of the light Beidou RTK differential system.

Table 2 Test parameters

No. of test	Mean flight speed /m·s^{-1}	Mean flight height/m	Mean temperature /℃	Mean humidity /%	Mean speed and direction /m·s^{-1}
Treatment 1	1.26	13.24	24.29	43.7	2.15/Southeast
Treatment 2	1.31	13.36	24.29	43.7	2.11/ Southeast
Treatment 3	1.31	10.65	24.20	46.2	2.14/ Southeast
Treatment 4	1.42	10.84	24.20	46.2	2.12/ Southeast
Treatment 5	1.28	6.86	23.60	50.2	2.05/ Southeast
Treatment 6	1.31	7.08	23.60	50.2	2.00/ Southeast
Treatment 7	1.33	6.94	21.60	55.9	1.90/ Southeast
Treatment 8	1.38	6.84	21.60	55.9	1.96/ Southeast

3 Data processing method

The testers put on disposable gloves and prepared the envelopes numbered in advance. After all the sampling cards were dried, they were collected one by one and taken back to the laboratory for scanning. The data processing software was DepositScan (developed by the US Department of Agriculture), the software can automatically obtain the droplet deposition, coverage per unit area, droplet number and droplet size.

3.1 Coefficient of variation

The coefficient of variation is used to describe the degree of variation and uniformity of the same set of data, in this test, it is used to describe the change range of droplet deposition, unit area coverage and droplet size of each sample in the same group, the larger the coefficient of variation, the worse the uniformity. The uniformity of distribution mentioned below is calculated based on this, the coefficient of variation (CV) was calculated as follows:

$$CV = \frac{s}{\overline{X}} \times 100\% \quad (1)$$

$$S = \sqrt{\sum_{i=1}^{n} (X_i - X)^2 / (n-1)} \quad (2)$$

where, S is the standard deviation; X_i is the droplet deposition (μL/cm^2), droplet percent area coverage (%) and droplet volume diameter (μm); $\overline{X}$ is the average value of each sample, n is the number of sampling points in each group.

3.2 Deposit level

The deposition level represents the percentage (%) of the droplet deposition in the application amount, k (%),

$$k = \frac{\beta_{dep}}{\beta_v} \times 10000 \quad (3)$$

where, β_{deo} is the droplet deposition per unit area, μL/cm^2; β_v it is the amount of spray liquid, L/hm^2.

3.3 Droplet drift rate and drift percentage

The calculation of the deposition level of droplet drift is the same as 1.3.2, according to the ISO22866 standard[39], the total measured value of spray drift β_T (%)

$$\beta_T = \int_2^{50} k(x)dx \quad (4)$$

The 90% drift distance is defined as the position where 90% of the total drift of the test is located.

4 Results and analysis

4.1 Test results of droplet deposition

Using the Tukey test method, the 8 treatments of sampling cards were analyzed by mathematical statistics, and the results showed that when the flight altitude, nozzle type and LAI were all changed, there was no significant effect on the first and second layer droplet deposition (P>0.05), but had a significant impact on the deposition in the stem layer. Treatment 2 (H=13.36 m) and Treatment 4 (H=10.84 m) had a significant effect on the flower stem layer of areca tree with LAI=1.65 (P=0.019). The data in Table 3 showed that the average droplet deposition of treatment 2 in the stem layer was 0.198 μL/cm^2, which was much higher than 0.049 μL/cm^2 of treatment 4 in the same layer. It was also found that the uniformity of droplet deposition distribution in this layer of treatment 2 was poor (CV= 71.80%). At the flight altitude of 7 m, when the nozzle type and LAI value changed respectively, the droplet deposition in the flower stem layer was significantly affected. The average deposition of treatment 7 (H = 6.94 m, LAI = 0.91) in the flower stem layer was 0.304 μL/cm^2, which was the highest in the 8 treatments, with the deposition level of 40.51%. The mean value and distribution uniformity of droplet deposition of each treatment, and the significance of the difference between the deposition of each sampling layer under the same treatment were shown in Table 3, and the distribution and level of droplet deposition were shown in Figure 4.

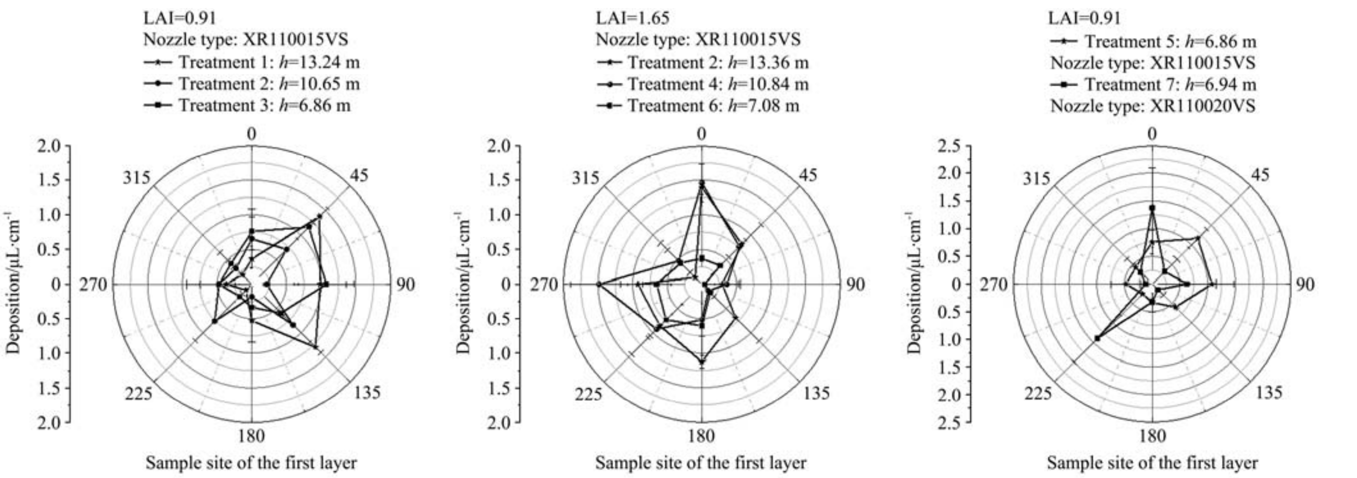
Table 3 showed that there was no significant difference in deposition between the first layer and the second layer for all treatments. Except for treatment 7, the deposition of the other 7 treatments were significantly different in the first layer and flower stem layer. Treatment 2, Treatment 3, Treatment 4, Treatment 5, Treatment 8 had significant differences in the amount of droplet deposition in the second layer and the flower stem layer.

When LAI=0.91, the first layer sampling point data showed that treatment 5 had the highest average droplet deposition value of 0.736 μL/cm^2, and the deposition level was 98.16%. Treatment 3 had the lowest average droplet deposition value of 0.499 μL/cm^2, and the deposition level was 66.59%. Treatment 1 and Treatment 7 had similar deposition levels of 78.61% and 76.57%, respectively, and the uniformity of droplet deposition in the same layer was the worst. The second layer sampling point data showed that treatment 5 had the highest average droplet deposition of 0.661 μL/cm^2 the deposition level was 88.16 %, the average droplet deposition amount of treatment 1, treatment 3, and treatment 7 were close, the deposition levels were respectively 48.64%, 47.6% and 55.12%, and the uniformity of droplet distribution of the 4 treatments was not much different. The sampling data of the flower stem layer showed that treatment 7 had the highest average droplet deposition value of 0.304 μL/cm^2, and the deposition level reached 40.51%, treatment 5 had the smallest average droplet deposition value of 0.062 μL/cm^2 and the deposition level of 8.28%. The droplet deposition levels of treatment 1 and treatment 3 were 19.51% and 10.45%, respectively. Treatment 1 had the best distribution uniformity, and treatment 7 had the worst distribution uniformity, which were 16.01% and 48.43%, respectively. The average total deposition of three layers in treatment 5 was the highest, treatment 3 was the lowest, treatment 7 had the best droplet penetration (CV=0.33), and treatment 5 was the worst (CV=0.76). When the leaf area index is about 0.91, if the key point is on the leaf surface of the canopy layer, it is recommended to operate the treatment 5 parameters. If the key point is on the flower stem layer, it is recommended to change the nozzle model and use the treatment 7, treatment 3 operation mode had the minimum droplet deposition, which is recommended to avoid.

Table 3 Droplet deposition characteristics and distribution uniformity

Test	Sampling location	Mean deposition /μL·cm^{-2}	Distribution uniformity/%	Mean percent area coverage/%	Distribution uniformity/%	Mean volume median Diameter/μm	Distribution uniformity/%
Treatment 1: h=13.24 m (LAI=0.91)	1	0.590±0.168 a	85.28	7.89±1.86 a	70.79	416±51 a	36.64
	2	0.365±0.075 ab	61.36	5.57±0.95 ab	51.38	360±12 ab	10.16
	3	0.146±0.008 b	16.01	3.05±0.13 a	12.06	263±6 b	6.02
Treatment 2 h=13.36 m (LAI=1.65)	1	0.701±0.150 a	64.33	10.19±2.03 a	59.73	478±43 a	26.68
	2	0.728±0.093 a	38.44	11.39±1.41 a	37.15	480±34 a	21.10
	3	0.198±0.050 b	71.80	3.41±0.80 b	66.57	311±17 b	15.11
Treatment 3: h=10.65 m (LAI=0.91)	1	0.499±0.082 a	49.50	6.57±0.86 a	39.43	423±28 a	20.20
	2	0.357±0.075 a	63.21	5.14±1.02 a	59.53	342±26 ab	22.43
	3	0.078±0.009 b	33.48	1.59±0.16 b	28.13	263±10 b	10.52
Treatment 4 h=10.84 m (LAI=1.65)	1	0.747±0.156 a	62.72	9.12±1.72 a	56.54	470±24 a	15.30
	2	0.672±0.163 a	72.77	7.71±1.57 a	60.87	458±41 a	26.93
	3	0.049±0.007 b	39.34	0.98±0.12 b	34.31	240±6 b	7.62
Treatment 5: h=6.86 m (LAI=0.91)	1	0.736±0.148 a	60.15	9.39±1.73 a	55.25	513±25 a	14.67
	2	0.661±0.142 a	64.44	8.23±1.63 a	59.28	432±40 a	27.62
	3	0.062±0.008 b	37.79	1.26±0.15 b	34.91	251±6 b	6.57
Treatment 6 h=7.08 m (LAI=1.65)	1	0.387±0.082 a	63.75	5.62±1.08 a	57.43	381±25 a	19.69
	2	0.355±0.079 ab	66.66	5.36±1.01 ab	56.71	343±15 a	13.39
	3	0.129±0.029 b	62.85	2.27±0.46 b	57.09	273±12 b	11.93
Treatment 7: h=6.94 m (LAI=0.91)	1	0.574±0.164 a	85.41	6.12±1.62 a	79.37	525±37 a	21.21
	2	0.391±0.101 a	77.32	4.61±1.03 a	67.31	459±56 a	36.61
	3	0.304±0.052 a	48.43	3.70±0.52 a	39.54	439±29 a	18.57
Treatment 8 h=6.84 m (LAI=1.65)	1	0.627±0.129 a	61.93	6.92±1.44 a	62.20	457±40 ab	26.42
	2	0.583±0.105 a	53.89	6.22±1.06 a	51.04	515±51 a	29.46
	3	0.135±0.031 b	64.42	1.81±0.29 b	45.29	351±21 b	17.13

Note: The data in the table are mean±SE. Data followed by different small letters are significantly different among different treatments at P<0.05 level by Tukey test. 1-the first layer, 2-the second layer, 3-the third layer, followed by the same letter are not significantly different.



a. b. c.

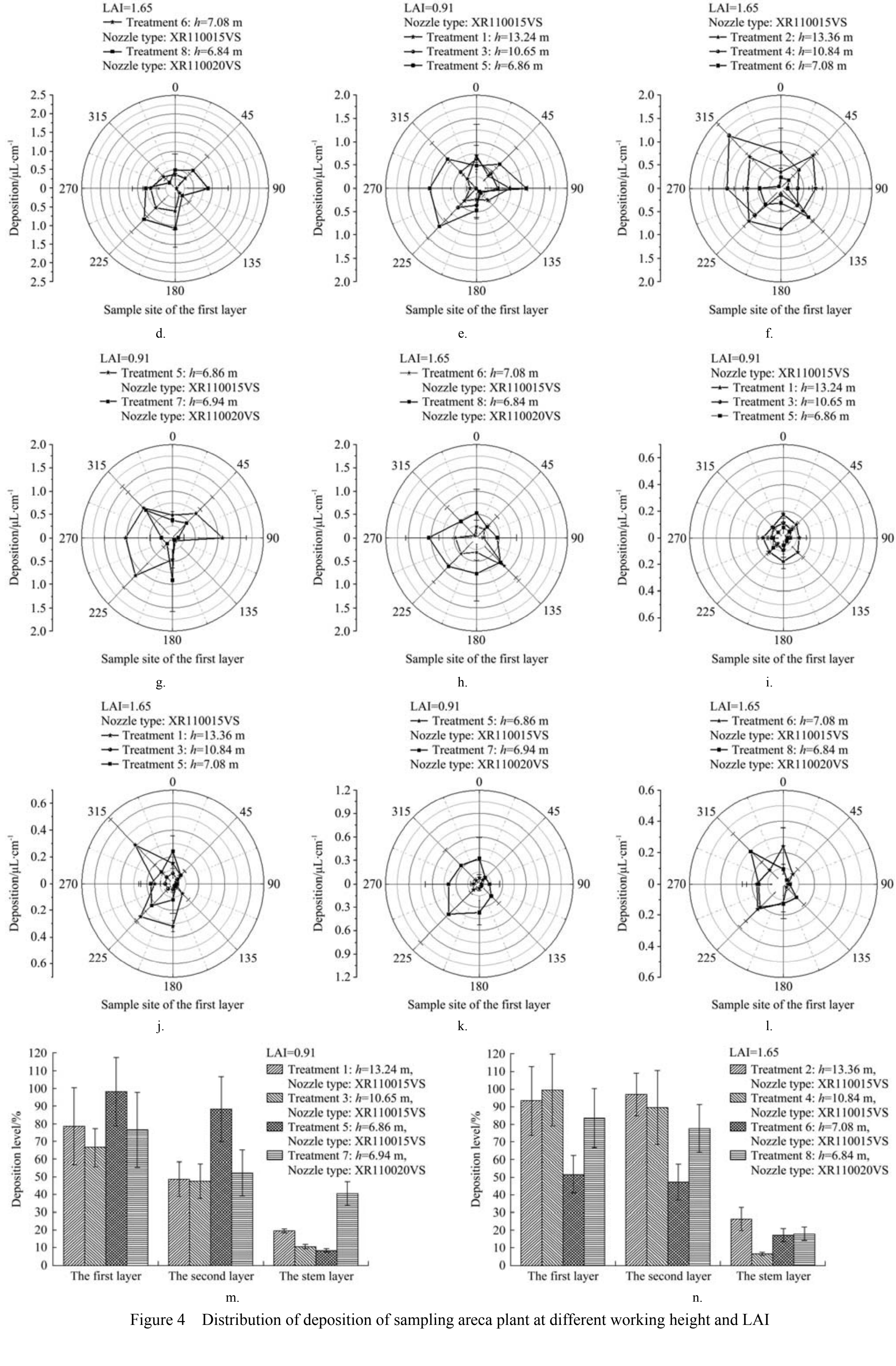


Figure 4 Distribution of deposition of sampling areca plant at different working height and LAI

When LAI=1.65, the first layer sampling data showed that treatment 4 had the highest average deposition value of 0.747 μL/cm^2, and the deposition level was 99.55%. Treatment 6 had the lowest average deposition value of 0.387 μL/cm^2 and the deposition level was 51.63%. Treatment 2 and treatment 8 had deposition levels of 93.44% and 83.60%, respectively. The data of the second layer sampling data showed that treatment 2 had the highest average deposition value of 0.728 μL/cm^2, and the deposition level was 97.05%. Treatment 6 had the lowest average deposition value of 0.355 μL/cm^2, and the deposition level was 47.32%. Treatment 4 and treatment 8 had the deposition level of 89.55% and 77.72% respectively. The sampling data of the flower stem layer showed that treatment 2 had the highest average deposition value of 0.198 μL/cm^2 and the deposition level of 26.37%. Treatment 4 had the smallest average deposition value of 0.049 μL/cm^2, and the deposition level was only 6.47%. The deposition level of treatment 6 and 8 were 17.17% and 17.95%, respectively. The average deposition of three layers in treatment 2 was the highest, treatment 6 was the lowest, treatment 6 had the best droplet penetration (CV = 0.48), and treatment 4 was the worst (CV = 0.78). When the leaf area index was 1.65, treatment 2 and treatment 4 was recommended when the spray focus on the canopy, treatment 2 can treatment 8 can be used in the flower stem layer, avoiding treatment 4.

When the nozzle type was Teejet XR110015VS and the flight altitude was 13.3 m and 10.7 m, respectively, the average deposition in the canopy of the sampled plants with LAI=1.65 was greater than that of the sampled plants with LAI=0.91. Areca trees with a higher leaf area index have an obvious droplet retention effect. However, this phenomenon did not occur when the flight altitude was about 7 m, at this flight altitude, the total deposition of the sampling plants with LAI=1.65 was the smallest, which was speculated to be related to the deposition caused by aerodynamic interference caused by rotor wind field, nozzle type, flight height, leaf area index and other factors. When the nozzle model was Teejet XR110002VS, the canopy interception effect was obvious when the operating height was about 7 m. When the flight altitude was about 7 m, the nozzle model Teejet XR110015VS had a higher amount of deposition on the first and second layers. Teejet XR110002VS had a higher deposition in the flower stem layer, and the total deposition amount on the two different leaf area index plants was similar and the penetration was better.

4.2 Test results of the coverage rate of droplets per unit area of each layer of areca nut plant

Using Turkey test to analysis 8 treatments data, the results showed that the percent area coverage of the 8 treatments in the first layer was not significantly different (P>0.05); in the second layer, treatment 1 and treatment 2 (P=0.03), treatment 2 and treatment 3 (P=0.01), treatment 2 and treatment 6 (P=0.02), treatment 2 and treatment 7 (P<0.01) were significantly different. Treatment 2 had a coverage rate of 11.39% per unit area, which was the highest among all treatments, it was speculated that it was related to the deposition and droplet size in this treatment. In the flower stem layer treatment 2 and treatment 3 (P=0.04), treatment 4 and treatment 1 (P=0.01), treatment 4 and treatment 2 (P<0.01), treatment 5 and treatment 1 (P=0.04), treatment 5 and Treatment 2 (P<0.01), treatment 7 and treatment 3 (P=0.01), treatment 7 and treatment 4 (P<0.001), treatment 7 and treatment 5 (P=0.001), treatment 7 and treatment 8 (P=0.03) were significantly different, that was, different flight altitude, nozzle models and leaf area index had a significant impact on the droplet coverage of the flower stem layer.

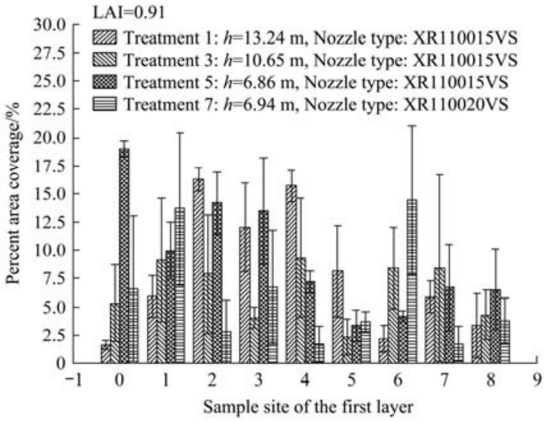
When the flight altitude was about 7 m and LAI=0.91, the nozzle model had a significant effect on percent area coverage. Teejet XR110002VS had a higher coverage of the droplets, and the leaf area index also had a significant effect on the coverage of the droplets. When the leaf area index was small, the percent area coverage of droplets in the flower stem layer was higher, that is, the higher the leaf area index is, the better the droplet interception effect is.

The average value, uniformity and difference of the droplet coverage of each layer of the 8 treatments were shown in Table 3, and the droplet percent area coverage distribution of each layer was shown in Figure 5. Except for Treatment 1 and Treatment 6, the significance of the coverage difference between the layers under the same treatment was basically the same as that of the droplet deposition. When LAI=0.91, the average percent area coverage of treatment 5 in the first layer was as high as 9.39%, and treatment 7 was at a minimum of 6.12%. The reason is that the droplet size of treatment 7 was significantly different from that of treatment 3 due to different nozzle types. In the second layer, treatment 5 had the highest average percent area coverage of 8.23%, and treatment 7 had the lowest coverage of 4.61%. The highest average percent area coverage of flower stem layer treatment 7 was 3.70%, and the lowest was 1.26% in treatment 5.

When LAI =0.91, treatment 5 and treatment 1 both can obtain a higher percent area coverage on the canopy of the plant, while treatment 1 and treatment 7 could obtain higher percent area coverage in the flower stem layer. When LAI=1.65, in the first layer, treatment 2 had the highest average percent area coverage of 10.19%, treatment 4 of 9.12%, and treatment 6 had the lowest value of 5.62%. In the second layer, treatment 2 also had the highest value of 11.39%, and treatment 6 had the lowest value of 5.36%. In the flower stem layer, the highest was 3.41% in treatment 2 and only 0.98% in treatment 4. When LAI=1.65, regardless of where the pests and diseases occur in the canopy or the stem, combined with the deposition data, it is suggested that treatment 2 can obtain higher droplet coverage per unit area.

4.3 Test results of droplet size

The distribution of Dv50 in the sampling layer of each treatment was shown in Figure 6. The Turkey test method was used for mathematical statistical analysis. The results showed that there was no significant difference in the size of Dv50 in the first layer of 8 treatments (P>0.05), and the Dv50 range was 416-525 μm. Treatments 8 and treatment 3, when the flight altitude , leaf area index and nozzle type were changed at the same time, there was a significant effect on the DV50 of the second layer (P=0.03), and the average DV50 was 515 μm and 342 μm respectively. Treatment 8 and Treatment 6, when the nozzle type changed, it had a significant effect on the Dv50 of the second layer of droplets (P=0.03), and the average Dv50 was 516 μm and 343 μm respectively; The effect of different treatments on the Dv50 of the flower stem layer was significantly higher than that of the first and second layers. There was a significant difference between treatment 7 and all other treatments in the flower stem layer (P<0.01), There was a significant difference between treatment 8 and other treatments except for treatment 2 (P<0.016), that is, only the change of nozzle type or all parameters had significant effect on Dv50 of spray droplet in flower stem layer, The average Dv50 of droplets in treatment 7 and treatment 8 was the highest, 439 μm and 351 μm, respectively.



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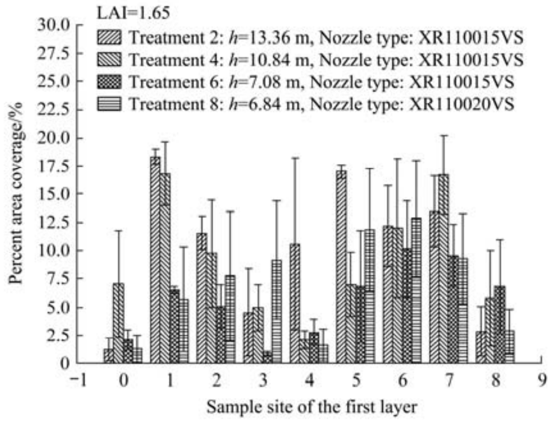

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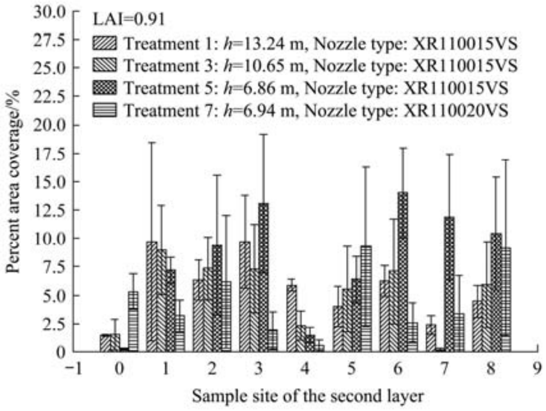

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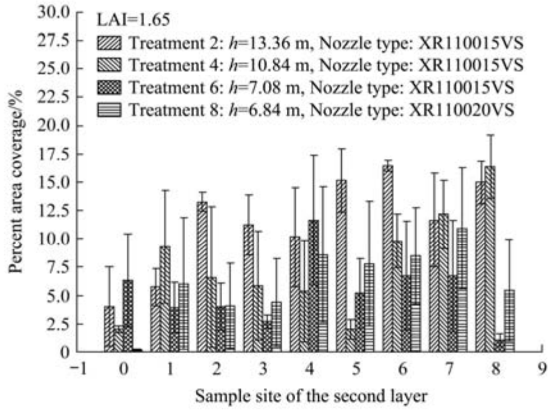

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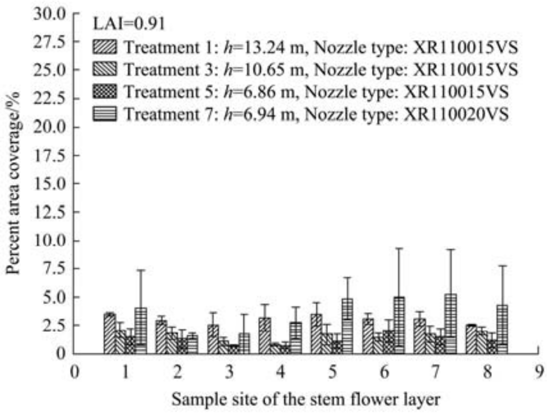

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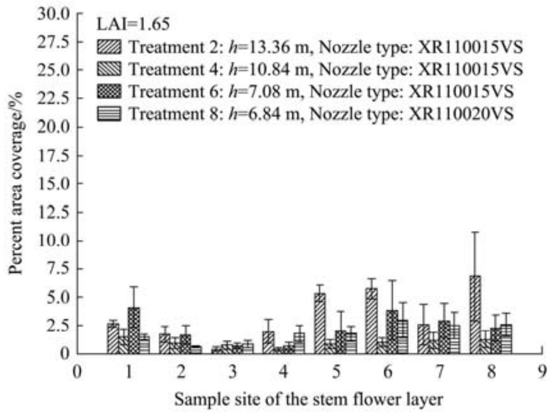
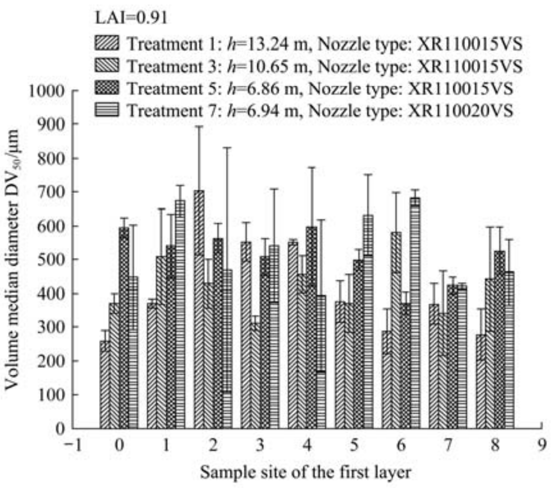


f.

Figure 5 Distribution of percent area coverage of sampling areca plant at different working height and LAI



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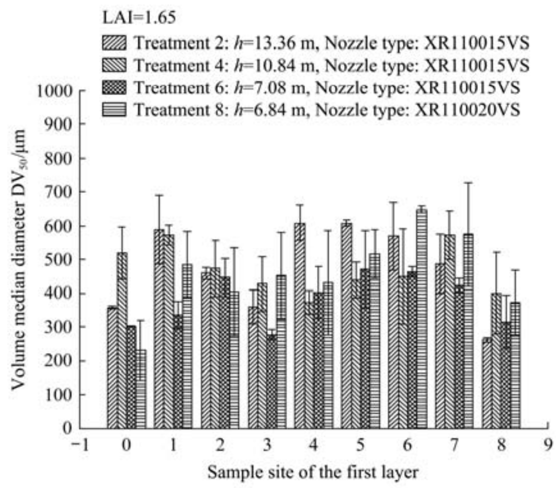

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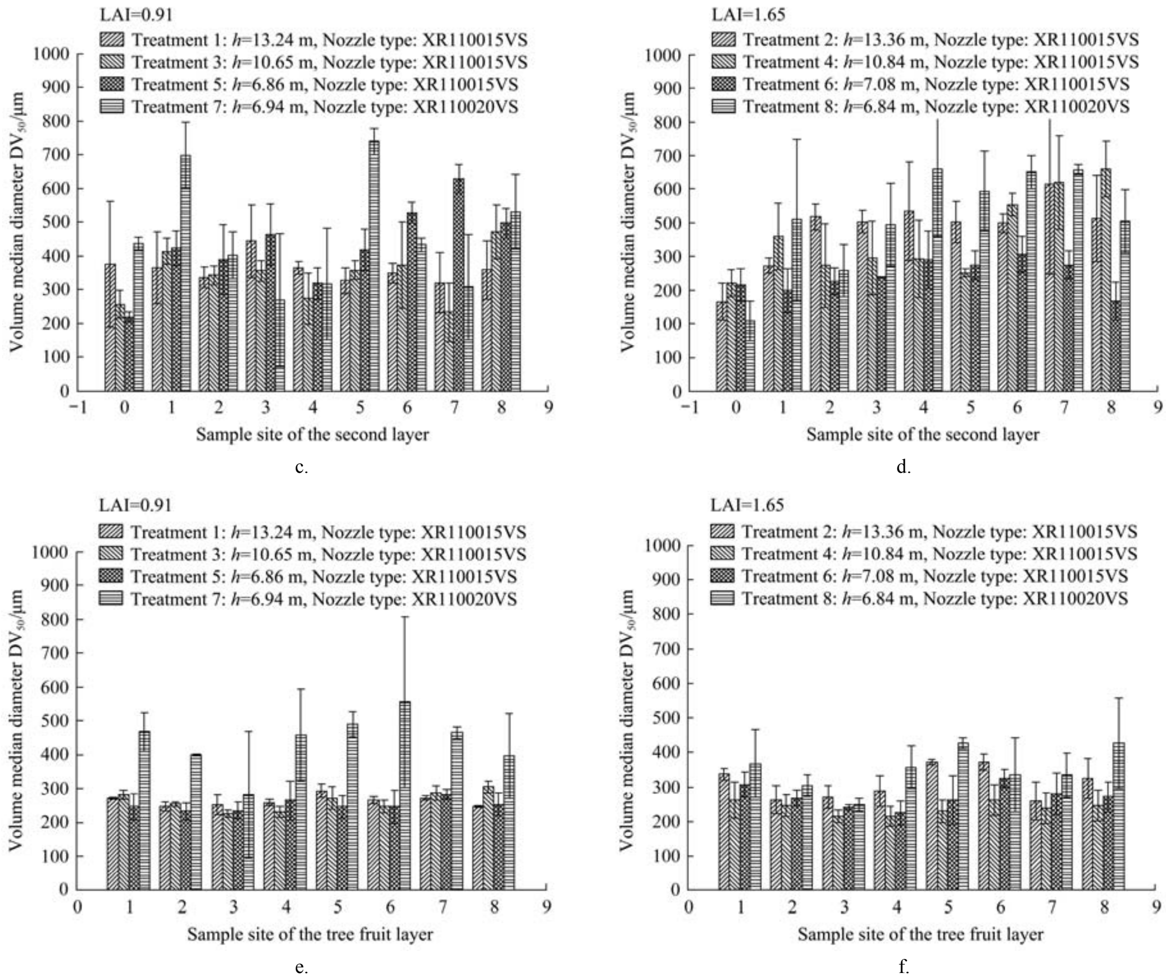


Figure 6 Distribution of droplets DV_{50} of sampling areca plant at different working height and LAI

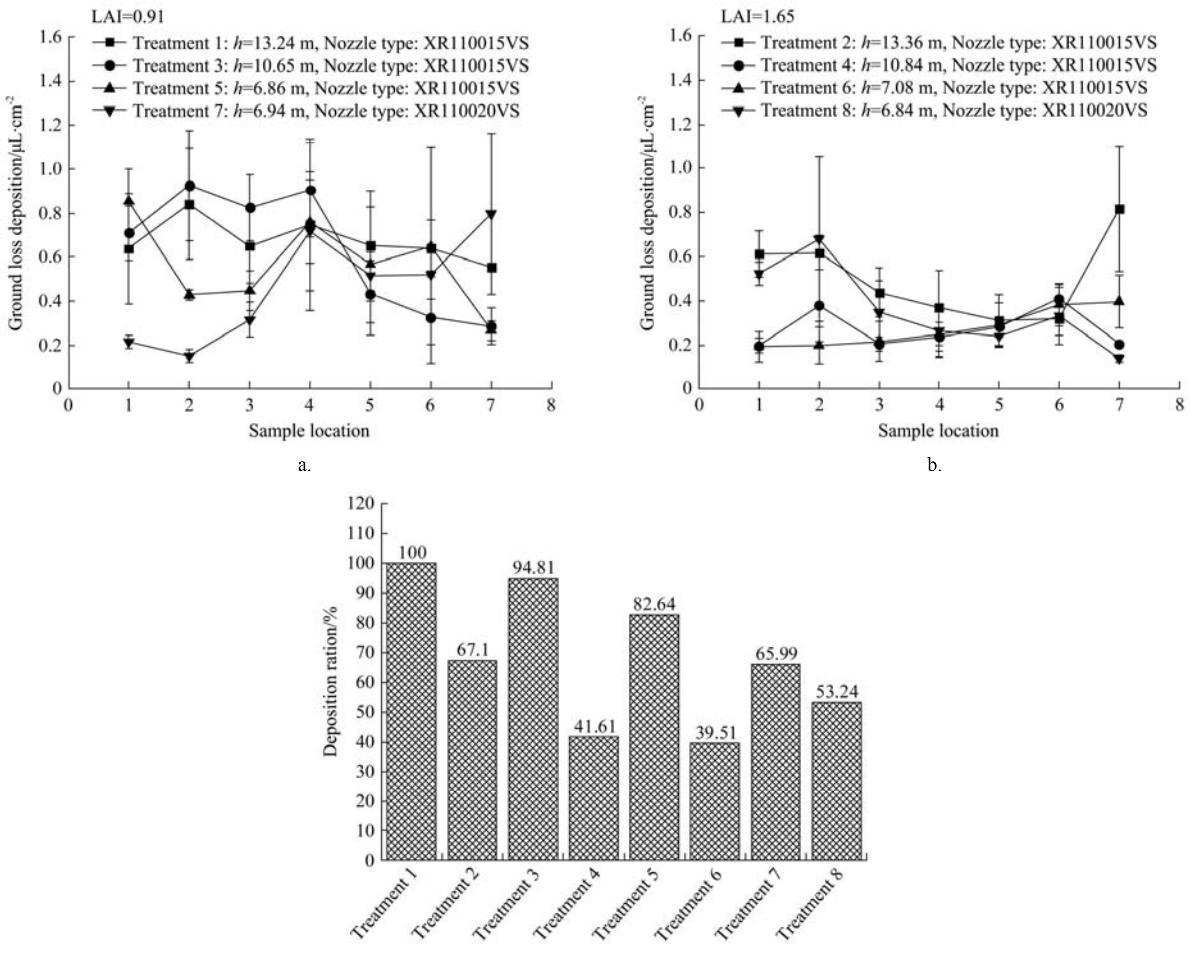
When LAI=0.91, in the first layer: the maximum average Dv50 of treatment 7 was 525 μm, and the lowest of treatment 1 was 416 μm. With the decrease of flight altitude, the average Dv50 value of droplets in the first layer increases, and the distribution uniformity of treatment 5 was the best (CV = 0.15), the average value of droplet Dv50 of treatment 1 was 513 μm, Treatment 1 had the worst distribution uniformity in this layer (CV=0.37), the average droplet Dv50 was 416 μm. In the second layer, the average Dv50 of droplets in treatment 3 was the smallest, and that of treatment 7 was the largest, which was 342 μm and 459 μm, respectively. Treatment 1 had the best distribution uniformity (CV=0.10), and treatment 7 had the worst (CV=0.37). In the flower stem layer, the difference of droplet Dv50 between treatment 1, treatment 3 and treatment 5 was not significant, ranging from 250 to 263 μm. The uniformity of the distribution of each layer was good, and the coefficient of variation can be as small as 0.06. The Dv50 of treatment 7 was the largest, reaching 439 μm, and the distribution uniformity was the worst (CV = 0.19). Treatment 1 was due to its smaller droplet DV50 increases its coverage per unit area. When the working height was about 7 m, the Dv50 of the two types of nozzles were relatively high, and should be selected according to actual needs. The results showed that treatment 5 in the first and second layers, treatment 7 and treatment 1 in the flower stem layer could obtain higher deposition, percent area coverage and better distribution uniformity than other treatments. Treatment 1 increased its percent area coverage due to its smaller droplet Dv50. When the working height was about 7 m, the Dv50 of the two types of nozzles were relatively high, which should be selected according to the actual needs.

When LAI = 1.65, in the first layer: the maximum Dv50 value of treatment 2 was 478 μm, the lowest was 381 μm in treatment 6, the distribution uniformity of treatment 4 was the best (CV = 0.15), the average value of droplet Dv50 was 470 μm, and the distribution uniformity of treatment 2 was the worst (CV = 0.27), the average Dv50 value of treatment 6 was the smallest, and treatment 8 was the largest, which was 515 and 343 μm, respectively The results showed that treatment 6 had the best distribution uniformity (CV = 0.14), and treatment 4 had the worst (CV = 0.27). In the flower stem layer, the average Dv50 value of treatment 8 was 351 μm, treatment 4 was 240 μm, The results showed that: compared with other treatments, treatment 2 could obtain higher droplet deposition, percent area coverage and better Dv50 distribution uniformity.

4.4 Test results of ground loss droplets

The distribution of each treatment in the ground droplet sampling area was shown in Figure 7. The Dunn sider (pro) test method was used to conduct statistical analysis on 8 treatments of data. The results showed that treatment 3 and treatment 4 ($P<0.05$) only changed the LAI value, treatment 2 and treatment 3 ($P<0.05$) changed the height and LAI value at the same time, while treatment 2 and treatment 7 ($P<0.05$) changed the operation height, LAI value and nozzle type at the same time, which had significant effect on the ground loss droplet deposition, while the other treatments had no significant effect.

Integrate each treatment in Figure 7 on the horizontal axis to obtain the total ground loss deposition of the test. Take the total deposition volume of treatment 1 as 100, and compare the values obtained by other treatments and the droplet deposition volume of each treatment at each sampling point, the average value was shown in Figure 7. The average deposition amount of treatment 1 at each sampling point was 0.675 uL/cm^2, and the deposition level was 89.33%. It can be seen from Figure 7 that under the same operating height and nozzle type, the droplets deposited on the ground with a low LAI were greater, which was speculated to be related to the growth morphology of the areca plant. The areca canopy leaves were concentrated in the crown and appear Distributed at a certain angle, the height of the trunk was about 2-3 m. The smaller the tree age, the larger the gap between the trunk and between the tree, and the larger gap in the center of the tree, resulting in the droplet deposition.



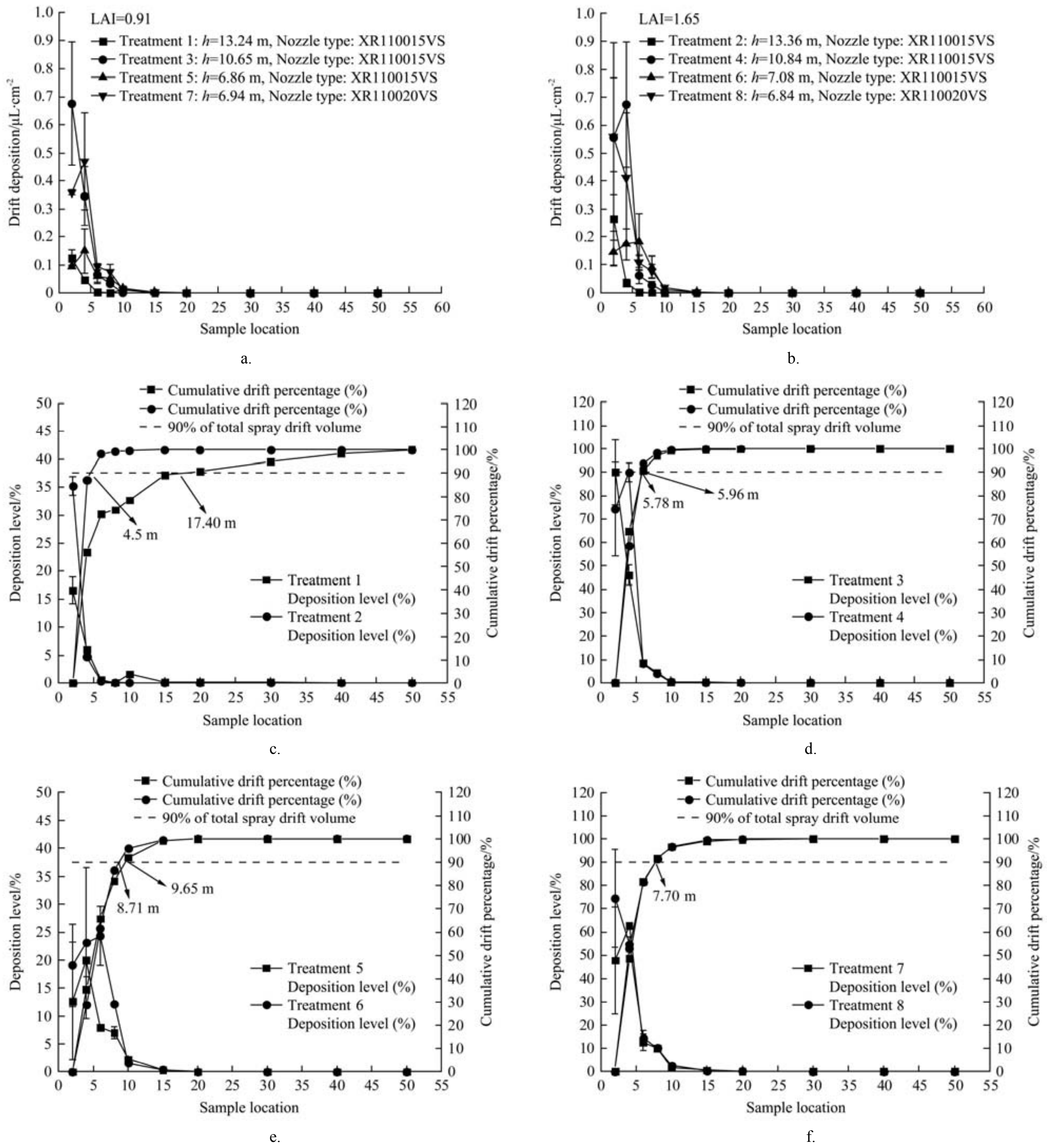
Note: The total deposition amount of each treatment in Figure 6c is the ratio to treatment 1.

Figure 7 Distribution of droplets of ground loss at different working height and LAI

Treatment 1 had the largest amount of droplet loss on the ground, and treatment 6 had the smallest amount of deposition, accounting for 39.51% of treatment 1. When the Teejet XR110015VS nozzle was working, as the flight altitude from 13.3 m to about 7 m, LAI=0.91, the total droplet loss rate on the ground was 100%, 94.81% and 82.64%. When LAI=1.65, the ground droplet loss was 67.1%, 41.61% and 39.51%. When only changing the nozzle model to Teejet XR110002VS, the operating height was about 7 m, LAI=0.91, the total droplet loss rate of treatment 5 and treatment 7 was 82.64% and 65.99%, respectively. LAI=1.65, the ratio of the total loss of ground droplets in treatment 6 and treatment 8 was 39.51% and 53.24%, respectively. When the Teejet XR110002VS nozzle was operated at a height of 7 m, the droplet deposition, percent area coverage and the droplets lost on the ground were similar, but the droplet deposition at the flower stem layer was poor.

4.5 Test results of droplet drift distribution

The distribution of deposition at the sampling points of 8 treatments was shown in Figure 8a and 8b, and the distribution of drift percentage, 90% drift distance and cumulative drift percentage was shown in Figure 8c-8f. The Turkey test was used to analyze the droplet deposition of 8 treatments of drift zone sampling points. The results showed that there was no significant difference among all treatments (P>0.05). Figure 8 showed that the 90% drift distances of the 8 treatments were 5.78, 5.96, 8.71, 9.65, 17.40, 4.5, 7.70 and 7.70 m, respectively. According to the abscissa integral of each treatment in Figure 8a and 8b, the cumulative drift percentage was obtained. The total test drift of treatment 1 was set as 1, and all treatments was compared to treatment 1 and obtained: 1:0.75:0.52:0.33:0.14:0.16:0.81:0.87. The data showed that the 90% drift distance of treatment 5 was the farthest and treatment 6 was the closest, the total drift distance of treatment 1 was only 5.78 m, but its total drift was the largest among all treatments, which was related to the deposition level and deposition in the drift area. The flight altitude of treatment 5-8 was about 7 m, and the total drift of teejet xr110002vs was about 5 times that of teejet xr110015vs; when the height was above 10 m, the total amount of drift of treatment with higher LAI was less, but at the flight altitude of about 7 m, the difference was not obviously. General drift test focuses on 90% drift distance, but the test found that distance was only one of the factors reflecting drift. The evaluation of drift should be combined with the total drift and the drift distance. When setting the safety zone, focus should be placed on the problem of droplet deposition at the initial boundary of the drift zone. In this test, sampling points with a deposition level of up to 90% can be measured within 4 m of the drift zone.



Note: Number in figure indicates the downwind distance corresponding to 90% drift accumulation.

Figure 8 Downwind drift characteristic for each drift sampling line at different height and LAI

5 Conclusions

The experimental variables were the flight altitude of the multi rotor UAV, LAI and the nozzle model. The field spray tests were carried out on areca trees. The droplet distribution characteristics of droplets in the canopy, trunk, ground and drift area of areca were obtained.

1) When the LAI is 0.91, it is suggested to select the flight altitude of 7 m and the nozzle type teejet xr110015vs. When the control focus was on the flower stem layer, it was recommended to select the operation height of 7 m and the nozzle type teejet xr110020vs. When leaf area index (LAI) is 1.65, it is recommended to select 13 m flight altitude and teejet xr110015vs.

2) Under the same nozzle type and flight altitude, the droplet deposition on the ground with low LAI was higher, which was related to the planting density and growth morphology of areca nut. When the nozzle model was Teejet xr110015vs, LAI was 0.91, and flight altitude was 13 m, the highest ground loss droplet deposition level was 89.33%, and the lowest was 35.29% when the operating height was 7 m and the LAI was 1.65.

3) The results showed that the 90% drift distance was 4.5-17.40 m, the nozzle model was Teejet XR110015VS, the flight altitude was 13 m, the total drift was the largest when the LAI was 0.91, and the smallest was at the flight altitude of 7 m, which was

about 14% of the former. It was found that the total amount of drift and 90% of the drift distance should be considered comprehensively in evaluating drift. For those with a larger total drift but a smaller distance of 90%, the initial position of the drift zone should be focused on the deposition.

This paper analyzes the application of multi-rotor plant protection UAV in areca nut tree from three aspects of areca nut plant, ground loss and drift area. The overall data was objective and the spraying effect was acceptable. However, the distribution uniformity of droplet size, deposition and percent area coverage needs to be improved, and the droplet size was generally larger, which can be used in rotor wind field distribution, flight altitude and nozzle structure optimization. In order to improve the deposition level of droplets and reduce the drift and loss of droplets, more uniform and smaller droplet volume and diameter were obtained.

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