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COMPARE EFFICACY BETWEEN KNAPSACK SPRAYER AND UAV SPRAYER APPLICATION IN CHEMICAL SPRAYING: A CASE STUDY OF GARLAND CHRYSANTHEMUM

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ABSTRACT

In the field of pesticide spraying for crop diseases and insect pests, the deposition structure of pesticide droplet includes coverage rate, droplet diameter, and droplet coverage density, which is one of the most important factors affecting the spraying effect.

In this study, two spraying devices, knapsack sprayer and unmanned aerial vehicle (UAV), were used to spray twice on the leaf front and back of Garland Chrysanthemum, the relevant parameters were obtained, and the effects of spraying and pest control were evaluated by Water-Sensitive Paper and Sticky Insect Paper.

This study is expected to pave the way for the use of knapsack and UAV sprayers in Taiwan and other areas for accurate pesticide application on Chrysanthemum crops.

At the result of spraying on leaf front, the droplets number of UAV was more than knapsack sprayer's (1663 verse 1081), while the coverage rate of knapsack sprayer was higher than UAV's (38.7% verse 25.8%). The droplet diameter of UAV was smaller than knapsack sprayer (58.5µm verse 241.1µm); and the droplet coverage density of UAV was larger than knapsack sprayer's (49.3/cm2 verse 32/cm2).On the other hand, the droplet deposition sprayed by UAV on the leaf back was better than knapsack sprayer as well.

The above results showed that the parameters of UAV's droplet deposition were better than those of knapsack sprayer's. The completed evaluation of droplet deposition parameters listed in (Table12-Leaf Front) and (Table13-Leaf Back).

Besides, in terms of pest control effect, UAV performed slightly better than knapsack sprayer as well (83% verse 73%).

The result of the study might provide a reference for future researchers and farmers who are growing Garland Chrysanthemum to choose the suitable equipment and improve the spraying effect.

Keywords: Droplet deposition, Coverage rate, Droplet diameter, Coverage density

1. INTRODUCTION

Garland Chrysanthemum is a common crop in Taiwan, manual sprayer is the main method for pesticide application in leafy vegetable, and knapsack sprayers are widely use in Asia-Pacific region countries[1].According to "Agricultural Knapsack Sprayer Market", The Agricultural knapsack sprayer market is expected to grow annually by 10.2% (CAGR 2023 - 2030)[2].In addition, as the latest market share statistics, North America holds 35% of the market share followed by Europe at 28% while China and Asia Pacific are the emerging players in this market with a 22% market share[3].While in the case of the relatively small scale of arable land owned by farmers in Taiwan, there is still a place for the knapsack sprayer.

The advantages of using a knapsack sprayer is cheap to purchase, easy to operate and versatility of use in both wet and isolated situations. The major disadvantages include its limited field capacity and problems of accuracy of application. Field of too much or too little spraying will result in undesired application results.

On the other hand, in terms of the development of pesticide spraying, the Agricultural Committee of Taiwan’s government has been called by the Food and Agriculture Organization of the United Nations (FAO) to "Chemical pesticides will be halved in ten years" (Bureau of Animal and Plant Epidemic Prevention and Quarantine, Agriculture Committee, Executive Yuan, 2022), and announced that in 2019, the "first year of UAV precision agriculture and agricultural spraying application" have been launched.

Spraying techniques continuously developed in recent decades, “Unmanned aerial vehicles (UAVs), or aerial drones, are an emerging technology with significant market potential”[4].It could contribute to the more sustainable use of pesticides; however, these potential benefits cannot be realized without improving the available skill, device and data on UAV applications.

Refer to previous advances in related fields; several researchers from the results of their experiments mentioned that knapsack sprayers were superior to UAVs in terms of spraying effects. As Wang et al. (2019) identified the UAV sprayer had a poor deposition uniformity and droplets penetrability, the deposition characterizations of the UAV sprayer were a lower area of coverage, a fewer spray deposits[5]. In their study, we observed CVs of 84.4% and 87.2% for knapsack sprayers and UAV sprayer deposits, respectively.

Daniele, S., Luisa, M., Marco, R., Riccardo, L., Stefania, Land Marco (2019) indicated in their comparative experiment of UAV and knapsack sprayer, the working capacity of the UAV was 1.6 fold that of the knapsack sprayer, the number of droplets and spray coverage with the UAV were lower than knapsack sprayer. This experimental case demonstrates UVA sprayer got the poor uniformity of droplet coverage in plants, which may be due to the fact that aerial application did not reach the vertical and cross-sectional effects. Also, UVA technology is limited by spraying at a maximum operating pressure of 0.4 MPa. And as far as the bigger droplet size, the nozzle performed not well, therefore centrifugal nozzles may be a good choice.

Xiao et al., (2020) in their experiments demonstrated that the UAV sprayer had a poor droplet coverage rate, droplet density, and deposition uniformity[6].Knapsack sprayer coverage rate and uniformity were better than UAV, but deposition worse than UAV. From the questions raised by the researcher, the upper leaf surface of the processed pepper grows quickly, covering the middle and lower leaf surface, resulting in low droplet coverage. If the centrifugal nozzle can be replaced or the downwash wind pressure can be appropriately increased, it may be a solution.

While some researchers put forward their experimental results, indicating under certain circumstances, the spraying effect of UAVs is not as good as that of knapsack sprayers, some researchers support that the spraying effect of UAVs is better than that of knapsack sprayers. Their opinions are as follows:

F A Rosedi and S M Shamsi, (2022) provided a comparative efficacy of drone application in chemical spraying at paddy field and stated that spraying with a power sprayer is more efficient than a knapsack sprayer, the use of drones in chemical spraying saved time and made the spraying process faster[7]. In this webinar article, in terms of comparing the equipment used, the researcher only discusses efficiency issues such as operating manpower, equipment energy, and operating time, without comparing parameters such as spray droplet size, uniformity, and coverage. It is less easy to observe spray results in terms of functionality.

Wei, Xu, Liu, Yang, and Chen (2020) expressed when sprayed by plant protection UAVs, the

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decrease rate of the UAV spray to S. frugiperda larvae is higher than sprayed with a knapsack sprayer[8]. In the online paper, the authors found that because the hairs on corn leaves make it easier for droplets to bounce and splash, it is more difficult for droplets to wet and spread across the leaf surface.

Shan et al., (2021) pointed out, the percentage of spray coverage is an important parameter of droplet deposition and an important indicator of evaluating spray effectiveness. In their research shows the percentage of spray coverage of droplets varied from different spray volumes and droplet sizes. When the spray volume was increased, the percentage of spray coverage increases with the increase of droplet size.

Parmar R P., Singh S K., Singh M. and Verma A. (2022) conducted a comparison of drone and knapsack sprinkler spraying technologies for bean crops and it was found that UAV spraying performed better in terms of average droplet size[9]. In the journal, the researchers found that UAV sprayers had smaller average droplet sizes compared to knapsack sprayers. This may be due to the use of ultra-low volume (ULV) nozzles, and the downdraft pressure created by the drone's propellers to break down the droplet particles into smaller sizes. Therefore, UAVwas better than knapsack sprayers in terms of spray droplet size, droplet density, and actual control effects on pests (B. Tabaci).

As mentioned above, each has its advantages and disadvantages whether uses knapsack sprayers or UAV-base sprayers. Therefore, this study was tasked with proposing the comparisons of efficacy between knapsack sprayers and UAV sprayers to observe which sprayer performs better, the specific objectives of this study were to (1) study the effect of droplet deposition, which include droplet number, droplet coverage, droplet size and droplet density,[10] (2) study the control effect of two pesticide sprayers on Garland Chrysanthemum pests and diseases.

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2. Background Knowledge

2.1 Knapsack sprayer

Human Spray Barrel S-16
https://www.tw-sato.com.tw/

SF-25
https://www.tw-sato.com.tw/

DAIWA DW-1600
https://tw.bid.yahoo.com/item

Figure 1: Three common agricultural knapsack sprayers in Taiwan

Knapsack sprayers come in many different forms (Figure 1), but the basic components and requirements for use are the same. These components contain containers for chemicals, a manual pump to generate pressure, a nozzle for a filter system that reduces clogging, a control valve that controls the pressure and rotation of the sprayer, and the entire sprayer generates droplets through the use of this component.

The advantage of using a knapsack sprayer is that it is cheap to buy, easy to operate, and has a wide range of uses. The advantages and disadvantages of the three knapsack sprayers are described below:

2.1.1 Human spray barrel S-16

This kind of iron barrel sprayer, in addition to being relatively bulky, has to be shaken while pulling to spray out pesticides, which is uncomfortable to use. The back is hard and has no support, which does not conform to ergonomics. Carrying it all day is too much.

2.1.2 SF-25

This is a sprayer with a larger capacity, which is more suitable for large areas of land or fields. It can be sprayed in a larger range, and its water output is about 3 ~ 8L/min. Many farmers use this style in the field, but compared with the other two, this style is relatively louder.

2.1.3 DAIWA DW-1600

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This agricultural sprayer has a medium spray volume, and it is the most entry-level model on the Internet in Taiwan, except for the good price. The body of the barrel is made of more durable PP material, which is anti-collision and anti-fall. The straps are also thickened with shoulder pads. There is also a pad on the place where the back and the body lean against, so that you will not keep hitting the bottle body when you are walking.

After comparing the advantages and disadvantages of the above sprayer, the last choice is DAIWA DW-1600. The knapsack sprayer DAIWA DW-1600 in this experiment is made in Taiwan. It is a 16L lithium battery sprayer, stainless steel spray rod, four kinds of variable nozzles, and an adjustable speed rotary switch.

2.2 UAVs type and composition

2.2.1 UAVs type

This study collected the types of multi-rotor plant protection UAVs in Taiwan in the past few years. The more common brands" (DJI), (DROXO), (FUNII), (ALIGN), (Earthgen-Tech) and (Super)", etc. are shown as (Figure2). (Of course, in recent years, other aircraft companies in Taiwan have launched plant protection UAVs one after another, so the study won't narrate much here), and chose the DJI MG-1S plant protection UAV, which is highly versatile in Asia, to spray crops.

It is expected that the different characteristics and advantages and disadvantages of the plant protection UAV will be verified through the comparison of the spray test with the agricultural knapsack sprayer.

DJIMG-1S
http://www.dji.com/zh-tw

DROXO
https://www.droxotech.com/

FUNII
https://a3funii.com/

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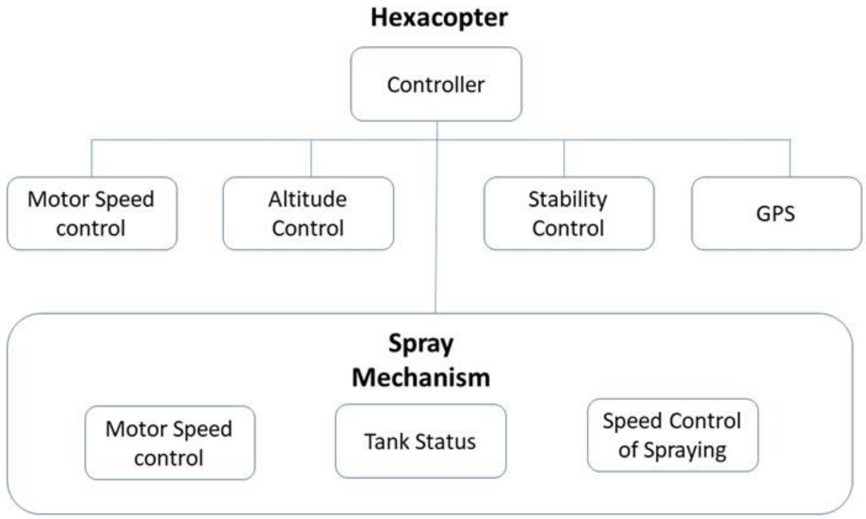
Figure 2: Six common types of agricultural UAVs in Taiwan

The Food and Agriculture Organization of the United Nations (FAO) and the International Telecommunication Union (ITU) published a special issue on "Use of Drones in Agriculture" in 2018, explaining that countries around the world use UAVs to combine satellites, global positioning systems (GPS), and the Internet of Things (IOT), artificial intelligence (AI) and wireless sensor network (WSN) and other smart technologies to conduct all-round agricultural application research and development.

The precision agricultural spraying technology using UAV spraying is expected to reduce the loss of pesticides, the harm to humans and the environment, and solve the problem of labor shortage, but the new method may bring new problems. Although the application of UVAs to agricultural spraying is a well-designed technology application, it is not as easy as expected in terms of promotion. For example, the technical threshold for equipment operation is high, the operation requires a license, there is no development of special pesticides for UVAs, and the procedures for applying for aerial spraying are complicated, etc., all of which will affect farmers' adoption of UVAs for aerial spraying.

2.2.2 UAVs composition

As to the composition, there are two parts in the module of the UAV sprayer, they are the spray module and the controller[11]. The spraying module contains the content of the spray, i.e. pesticide or fertilizer, and the controller section for activating the nozzles of the sprayer. Commands are received from a manually activated remote. The nozzles of the sprayer module will be activated by the GPS device. The components see Figure 3.



From: K,K.,H,M.,J,N.,R,P., and R,S http://www.kscst.iisc.ernet.in/spp/39_series/SPP39S/02_Exhibition_Projects/147_39S_BE_0564.pdf

Figure 3: Block diagram of an automatically controlled UVA based aerial pesticide sprayer

2.3 Crops

2.3.1 The living environment of Garland Chrysanthemum

The crop planted in this experiment is Garland Chrysanthemum, which is a semi-cold-resistant plant and likes a cool and humid climate. The optimum temperature for growth is 18-20°C. It grows poorly when it is above 29°C, and it grows slowly when it is below 12°C. It can withstand 0°C for a short time. There are many planting technology for Garland Chrysanthemum from "Agricultural Knowledge Portal", which can be entered keywords to browse.

2.3.2 Possible pests

Miner flies

Ladybug

Cutworms

Moth

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Aphid Noctuid Whitefly Thrips

Figure 4: Chrysanthemum common diseases and insect pests

From: https://diag.tactri.gov.tw/Search/CropPrevDetail?ResultId=19663

In order to understand the possible pests and diseases of Garland Chrysanthemum after germination, this study collected eight possible samples of pests in advance, shown as Figure4, and placed five sticky insect paper frames with recording strips on each of the A and B areas of the field for monitoring of diseases and insect pests. As the basis for the follow-up precise spraying, place it on site as shown in the Figure5.

Figure 5: Field monitoring sticky insect paper

2.4 Pesticides

The crop planted in this experiment is Garland Chrysanthemum. After monitoring by placing insect traps in the field, we can know what the pests and diseases are controlled by the crops, and we can implement targeted spraying on the target pests. Therefore, the next focus is on the deployment technology of pesticides.

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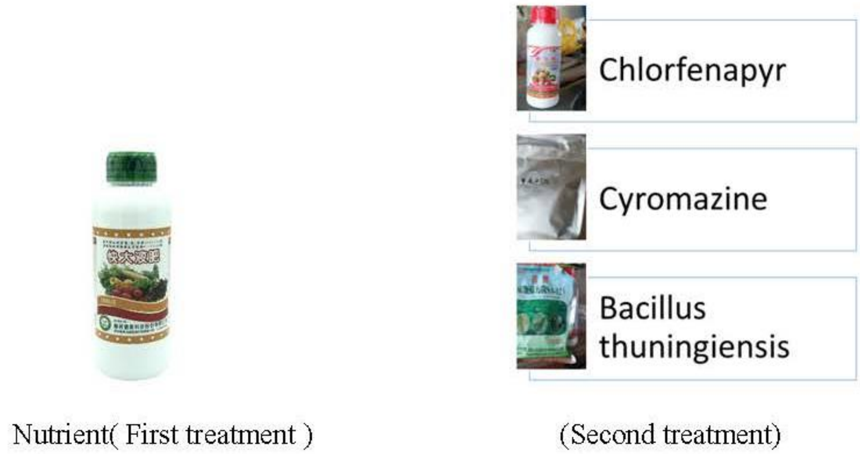

Figure 6: Four kinds of pesticides to control the pests of Garland Chrysanthemum

When planting a crop, multiple diseases and insect pests may be encountered at the same time, so more than two kinds of pesticides are required. For the crop Garland Chrysanthemum planted in this experiment, the required pesticides may be “Chlorfenapyr” to control Thrips and whitefly, and “Cyromazine” to control Liriomyza spp. “Bacillus thuningiensis” against bacterial diseases. When using multiple pesticides at the same time, it is necessary to mix them. Therefore, before formulating pesticides, it is necessary to understand the mechanism of action, pH and stability of commonly used insecticides and pesticides, as shown in Figure 6, so as to dispense pesticides carefully.

2.4.1 Mechanism of action of pesticides.

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Table 1: Mechanism of action, pH and stability of commonly used insecticides and pesticides

Pesticides	Mechanism	pH	stability
Pei Dan 50% SP	systematic	3-6	Decompose in neutral or alkaline
Idamide 9.6% SL	systematic	6-8	Stable at pH5-11
Tao Songs 22.5% EC	contact type	4-6	Hydrolyzed in alkali
Fipronil 0.3% GR	contact type	5-7	Slowly hydrolyzed in alkali
Dimethonine 2.8% EC	contact type	6-7	more stable in acid than in alkali
Nelisone 58% EC	contact type	5-7	Rapidly decomposes in alkaline water
Fenfali 20% EC	contact type	4-6	Decomposes rapidly in alkaline
Cyromazine 5% EC	contact type	6-7	Decompose in alkaline

From the Material R&D Group of the Agricultural Drug Toxicology Laboratory

It is stated in the materials of the Institute of Agricultural Drug Toxicology of the Agricultural Committee of the Executive Yuan of Taiwan "Questions and Answers on Rational Use of Pesticides—Applications"[12] The mechanism of action of pesticides is based on whether it migrates in the plant is divided into systemic pesticides and contact pesticides (Table1). Systemic pesticides are generally water-soluble and can migrate in plants. After contacting crops, pesticides can be absorbed through the application site of the plant. After being absorbed from the surface, stomata, water pores or roots, they will spread throughout the plant with the transport of water, and spread evenly into the plant body, although it will not cause local high residues on the plant body, but it is often not easily affected by factors such as rainwater washing, and the drug effect can last for a long time. Since the pesticide will be distributed in the plant body and cannot be removed by washing, it is not suitable to be used in the late cultivation or harvesting period. The contact pesticide refers to the direct contact of pests and diseases with pesticides to produce killing effect. The migration of contact pesticides in plants is small, and they are easy to adhere to the surface of plants or accumulate in the waxy structure. Therefore, the parts in contact with crops often form high residues.

2.4.2 pH

According to the principle of mixed use of pesticides, acidic pesticides such as most organophosphorus pesticides (pine) and commonly used synthetic pyrethrum (Ning) are mostly acidic pesticides, and should not be mixed with alkaline pesticides such as copper agents, lime substances or Bordeaux mixtures to avoid Poor efficacy or cause drug injury. When mixed, neutral pesticides, acidic pesticides or neutral pesticides and acidic pesticides do not produce chemical and physical changes to each other, so they can be mixed. There are also some pesticides that decompose under alkaline conditions, but the decomposition is relatively slow. They can be mixed with alkaline substances, but they must be used as they are prepared, otherwise precipitation will occur, and spraying on plants will not form a protective film, and the control effect will not be achieved.

2.4.3 Pesticide deployment technology.

After understanding the mechanism of action, pH and stability principles of the above commonly used insecticides and pesticides, refer to the pesticide deployment technology of the Agricultural Drug Toxicology Laboratory, including knapsack sprayers and unmanned plant protection machines. The steps are as follows[13]:

Step 1: Measure the dosage correctly:

According to the application area, refer to the plant manual to recommend the dosage per hectare, in exchange for the correct dosage of 1L/ha.

Step 2: Calculate the amount of water needed according to the dilution factor:

That is, the amount of medicine required for a certain area * the dilution factor = the final volume of the prepared medicine, the formula is as follows:

Recommended dosage (1L/ha)	A
Recommended dilution factor	B
Application area (ha)	C
Liquid medicine volume (liter)	D=A*C
Total potion volume (liter)	E=A*B*C
Water requirement (liter)	F=E-D
Flow (liter/ha)	G=E/C

The final volume of the prepared medicament is calculated with two kinds of spray equipment in the experiment respectively as follows:

Knapsack sprayer actual field area: 0.03ha

A= 1L/ha
B= 1000
C= 0.03(ha)
D= A*C=0.03(liter)
E= A*B*C=30(liter)
F= E-D=29.97(liter)
G= E/C=1000(liter/ha)

Refer to the instructions on the pesticide label or instructions or the plant protection manual, for example: when using 1 liter (or kilogram) of pesticide per hectare, dilute 1000 times. The total potion volume is 1000 liters.

UAV field actual area 0.03ha
A=1L/ha
B=20
C=0.03(ha)
D=A*C=0.03(liter)
E=A*B*C=0.6(liter)
F=E-D=0.57(liter)
G=E/C=20(liter/ha)

Step 3: Pesticide deployment:

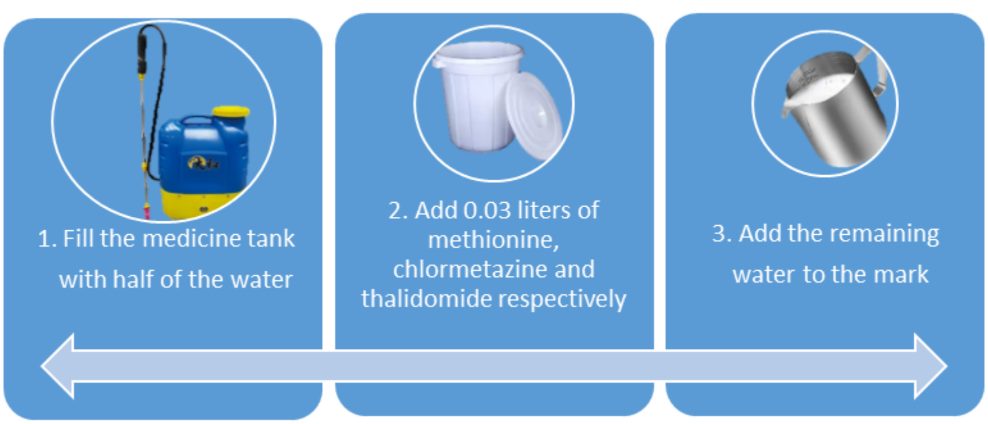

Figure 7: Dispensing steps

Three steps of Pesticide deployment (Figure7):

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(1) Put half the amount of water in the medicine barrel first.

(2) Liquid medicament: Add the medicament to the medicine barrel while stirring evenly, and then add the remaining half of the water.

(3) Solid medicine: Stir evenly in a small bucket in advance, pour it into the medicine bucket through a filter, and then add water.

3. METHODOLOGY

3.1 Conceptual Framework

This study is a field experiment, and the operation sequence of this experiment is to start from the selection of Garland Chrysanthemum crops, then observe what kind of diseases and insect pests may appear. The second, after the plants germinate which the study can refer to the pictures of several common diseases and insect pests of target plants provided by the national agricultural agency on the official website[14]. Third, select the appropriate nozzles, set the height and speed of the operation to spray before using knapsack sprayer and UAV. At last, take Water-Sensitive Paper and Sticky Insect Paper to test the effects of spraying and pest control. In short, the structure of this research explores how to conduct a test for the spraying effectiveness, namely for spraying distribution and drift effect by using the method of a knapsack sprayer versus UAV. The program concept for this experiment was shown in Figure 8.

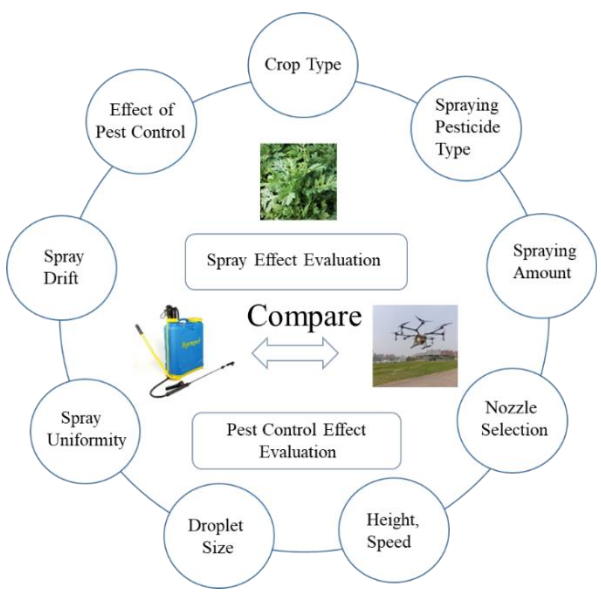

Figure 8: Research Concept

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3.2 Research Tool

The experiment was divided into two processes: spray deposition test and control effect of Garland Chrysanthemum test. All experimental tests are carried out in a fixed area, zone A, B, where will be conducted in 300 m2 (10*30 m) field respectively with 4m between each zone as a buffer zone.

To perform this experiment by comparing using knapsack sprayer versus UAV sprayer[15], the following information had been prepared and gathered:

3.2.1 Field plots

The spray test will be conducted in the area of the fields, about 0.06 ha, at Longyan located in the district of Yuanchang in Yunlin County (Latitude: 23°62'1.41 N "Longitude: 120°3'1.57"), the two treatments indicated as Figure 9 and Figure 10.

In the first treatment, Zone A and Zone B hold 28-meter-long droplet collection lines with an interval of 4 m respectively, included fourteen sampling points, which were placed one piece of WSP at every point, numbered as AS1-AS14 and BS1-BS14 from right to left.

Zone A and Zone B spraying will be performed by the manual sprayer and UAV from south to north with pre-set altitude and velocities within the optimal operational range. The bottom of the region was downwind drift test zone, and the right of the region was the neighbor field drift test zone. In addition, the real-time temperature, humidity, wind velocity, wind direction and other meteorological information will also be recorded during the experiment.

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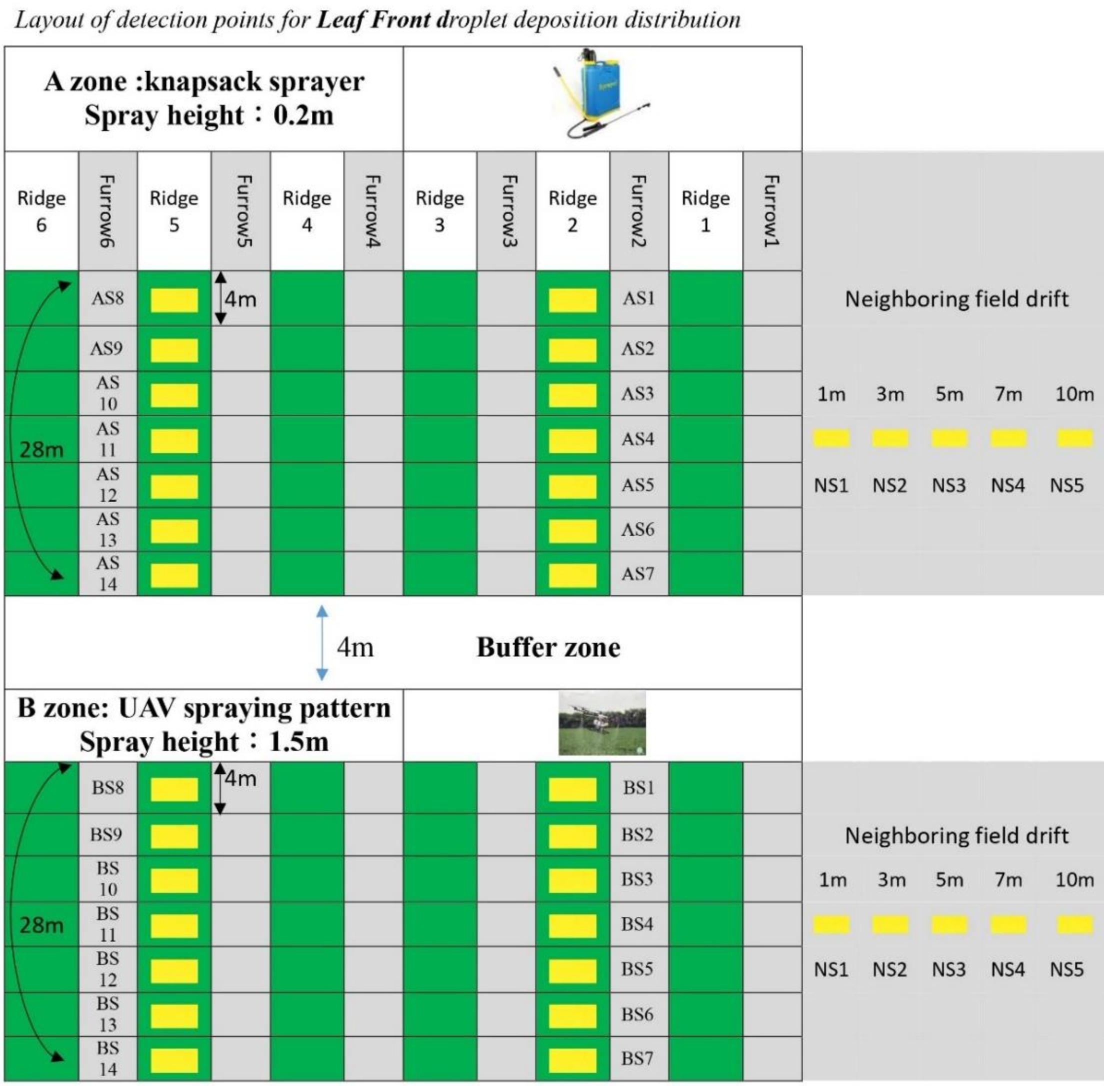

From Mat et al. (2018), Evaluation of the spraying dispersion and uniformity using drone in rice field application. MSAE Conference Paper, 7 & 8 February 2018, Faculty of Agriculture, University Putra Malaysia.

Figure 9: Layout of detective points for leaf front droplet deposition

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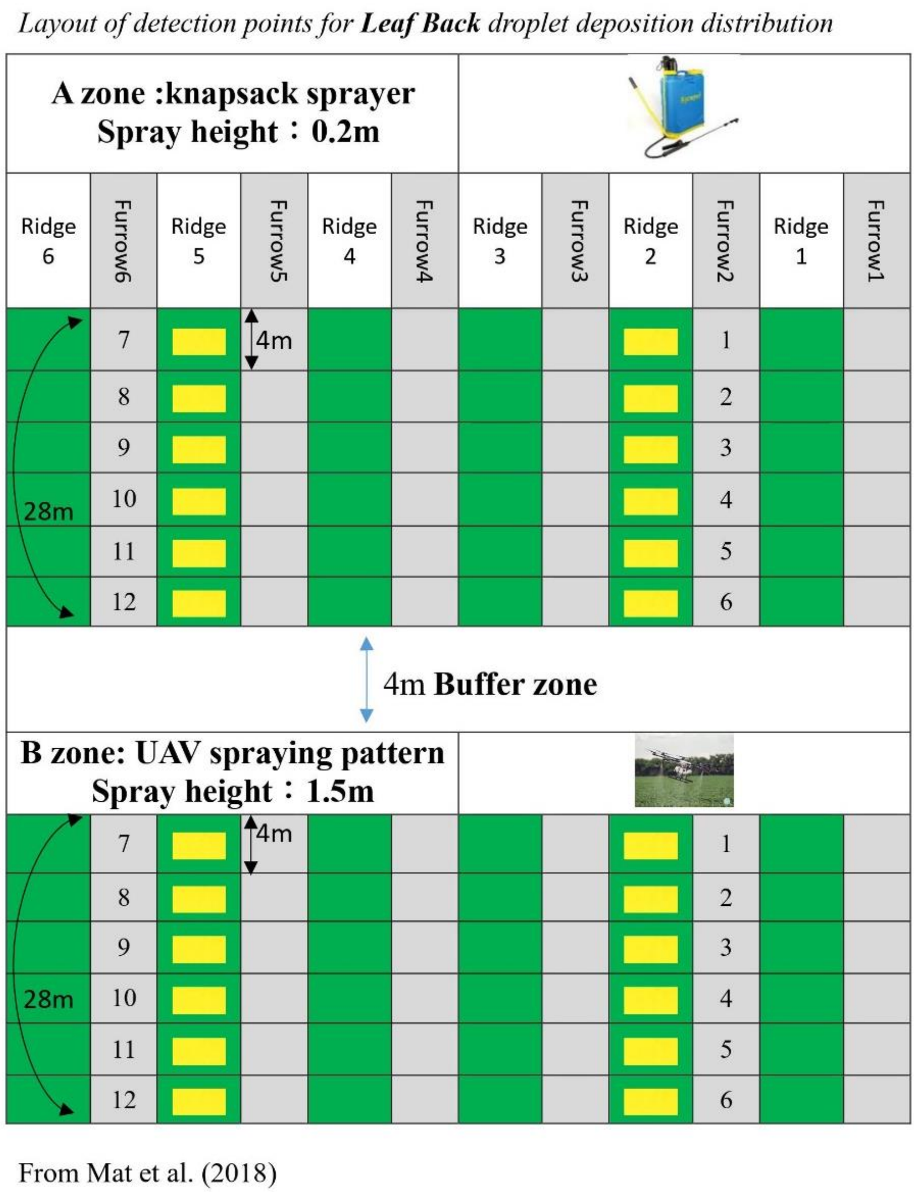

Figure 10: layout of detection points for leaf backdroplet deposition distribution

In the second treatment, there were the same condition in Zone A and Zone B as the first treatment, but the difference was that the second treatment only included twelve sampling points in each Zone, which were also placed one piece of WSP at every point, numbered as AS1-AS12 and BS1-BS12 from right to left.

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3.2.2 Knapsack and UAV reference equipment

Knapsack sprayer
DAIWA DW-1600

UAV：MG-1S sprayer

Figure 11: Two sprayers used in field trials

In this study used two sprayers (Figure 11), one equipment, Knapsack sprayer (16 L), will be used chiefly in pest control and in spraying fungicides or insecticides. It is a continuous type of sprayer with a fairly constant discharge rate.

The brief steps for using a knapsack sprayer mentioned as following：First of all, fill the tank with about half of the water needed, then add the required amount of pesticide to the tank. Close cap and agitate by shaking or inverting sprayer. Finally, add the remaining water, desired surfactant and repeat agitation to ensure the pesticide solution is well mixed.

Another equipment is the combination of an unmanned aerial vehicle (UAV) with a sprayer system, which has the potential to provide a platform for pest management. The power machine used for this study is from DJI UAV (Model: Mg1s).

Both of the equipment will be controlled at the desired test height. The knapsack sprayer was tested at about 0.2mand the UAV was tested at typical speed 1.5m.

Besides, according to the "Pesticide Field Test Guidelines" need to record the technical parameters of UAV spraying.

(1) Test data: including the implementation date, the address of the implementation site and the field map, the planning of the spraying flight path, the variety of the target crop and its growth period, the target pest, the name of the pesticide, the formulation of the pesticide, the dilution factor, the dosage, Information about spraying altitude from the ground and crown, flight speed, wind direction.

(2) Technical parameter information of the type of unmanned aerial vehicle: including type,

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fuselage length (mm), empty weight and take-off weight (kg), rotor diameter (mm), spray boom width (mm), number of nozzles, Nozzle model, spray pressure (kg/cm2), spray flow rate (L/min), and droplet size (μm), shown as(Appendix 2).

3.2.3 Two materials

(1) The droplets deposition on the leaves of crops were sampled with Water-Sensitive Paper, which were scanned at a resolution of 600 dpi with a scanner, and imagery software Deposit Scan (USDA, Wooster, OH, USA), and the droplet analysis software is used to check the droplet number, droplet size, coverage, density of the droplets[16].

(2) To count the number of sticky pests and record the control effect of pests and diseases with Sticky Insect Paper.

4. RESULTS AND DISCUSSION

In this study, after completing the field experiment according to the above mentioned research procedure, the number of droplets sprayed by the two spraying equipment, the samples of droplet diameter (um), the coverage rate (%), and the coverage density (cm2) were collected in (Appendix 3 and 4), which were closely related to the droplet deposition. As a result, relevant parameter analysis and discussion are proposed as follows:

4.1 Number of Droplet

4.1.1 Droplet quantity – leaf front

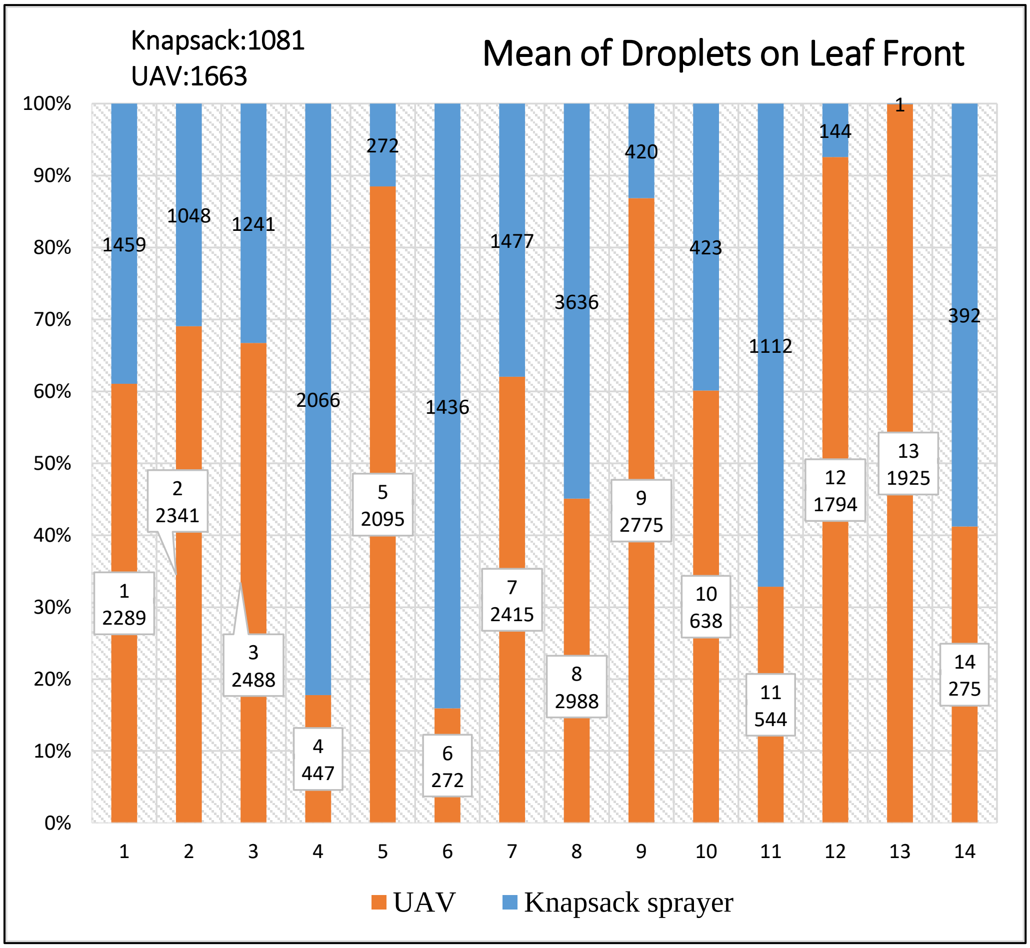

Figure 12: The mean of droplets on leaf front

Using two kinds of sprayers, the total average number of sprayed droplets was calculated with 14 pieces of Water -sensitive paper, which are 1081 for knapsack sprayer and 1663 for UAV, the total average number of sprayed droplets with UAV was higher than 1.5 times of knapsack sprayer (Figure12), with t test analysis such as Table2.

Table 2: Number of knapsack sprayer and UAV sprayer on droplet number - t test

Sprayer	Mean	Number of observations	Minimum	Maximum	Std. dev.	*C V*	*P -value*
Knapsack sprayer	1081	14	1	3636	960.6	0.89	0.128
UAV	1663	14	272	2988	1000.2	0.60	

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Independent sample t-test analysis results:

(1) In this study, an independent sample t-test was used to compare whether the mean numbers of knapsack sprayer and UAV were different.

(2) Knapsack sprayer samples 14, the average is 1081; UAV samples 14, the average is 1663.

(3) In the independent sample t test, the test statistic t value was -1.5724, and the probability value p value was 0.128, which did not reach the significant level of α=0.05, so the null hypothesis could not be rejected.

(4) Means of knapsack sprayer and UAV groups were not significantly different.

4.1.2 Number of droplets – leaf back

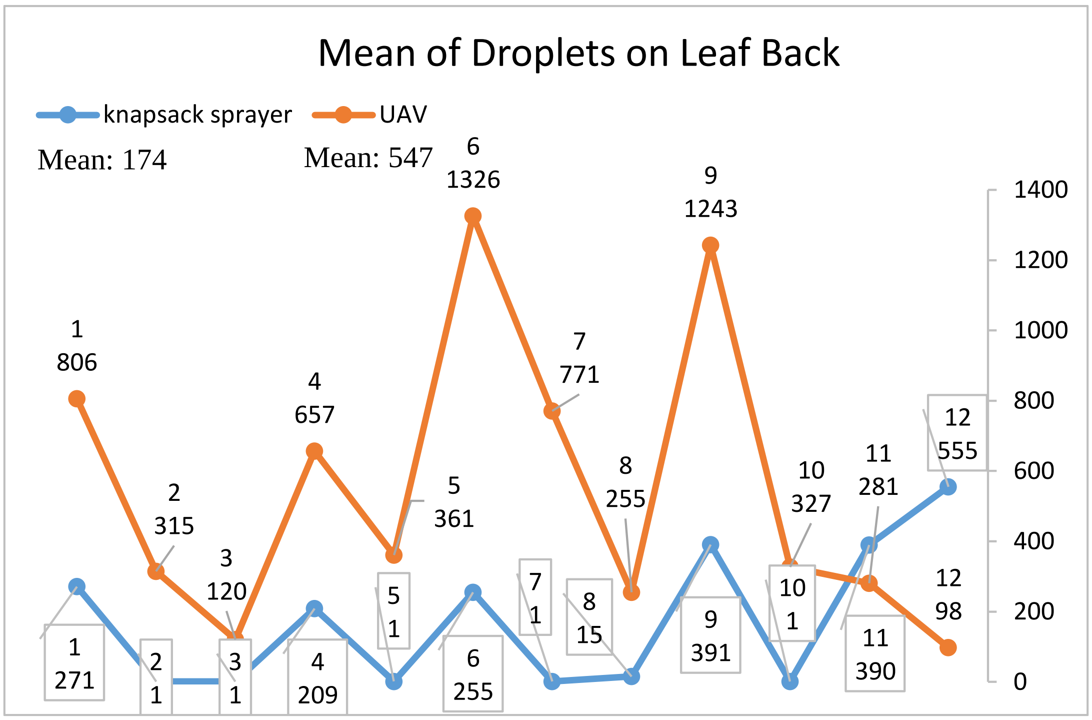

Figure 13: The mean of droplets on leaf back

Using two kinds of sprayers, the total average number of sprayed droplets was calculated with 12 pieces of water-sensitive paper, which are 174 for knapsack sprayer and 547 for UAV, the total average number of sprayed droplets with UAV was higher than 3.1 times of knapsack sprayer (Table3), p-value'*' 0.01< 0.05(p < 0.05) was considered a significant deference between the two

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groups (Figure13), with t test analysis such asTable3.

Table 3: Number of droplets on leaf back-t test

Sprayer	Mean	Number of observations	Minimum	Maximum	Std. dev.	*C V*	*P -value*
Knapsack sprayer	174	12	1	555	197.9	1.14	0.012
UAV	547	12	98	1326	415.3	0.76	

Independent sample t-test analysis results:

1. This study used an independent-samples t-test to compare the mean numbers of knapsack sprayer and UAV.
2. Knapsack sprayer samples 12, the average is 174; UAV samples 12, the average is 547.
3. In the independent sample t-test, the test statistic t-value is -2.8041, the probability value p-value is 0.012, reaching the significant level of α=0.05, so the null hypothesis is rejected and the opposite hypothesis is accepted.
4. Indicates that the means of the knapsack sprayer and UAV groups are significantly different. Among them, UAV is significantly larger than knapsack sprayer.

4.1.3 Discussion of droplet number

In spraying on the front of leaves, in the independent sample t test, the p value of the test statistical probability value was 0.1279, which did not reach the significant level of α=0.05, showing that there was no significant difference between the averages of the Knapsack sprayer and UAV groups; but in spraying on the back of the leaf, the number of droplets of the UAV was more than that of the backpack, and the p value of the test statistical probability value is 0.012, which has reached the significant level of α<0.05. After the two application, the UAV group effectively increased the number of droplets. Yuan Huizhu and Wang Guobin (2015) proposed, "each pesticide droplet has its killing range, which is called the droplet killing area or killing radius", it means that the more particulate matter sprayed by UAV, the better the control effect on pests and diseases.

The number of spray particles of the UAV was more than that of knapsack sprayer in both cases, mainly because the number of nozzles and the amount of water sprayed per minute were different. The UAV has 4 nozzles, and the water spray volume of each nozzle is 450ml/min, totaling 1.8L/min; 1.08L/min, so the UAV nozzle can produce more water spray, the number of droplets also increases.

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4.2 Droplet Coverage Rate

4.2.1 Droplet coverage on leaf front

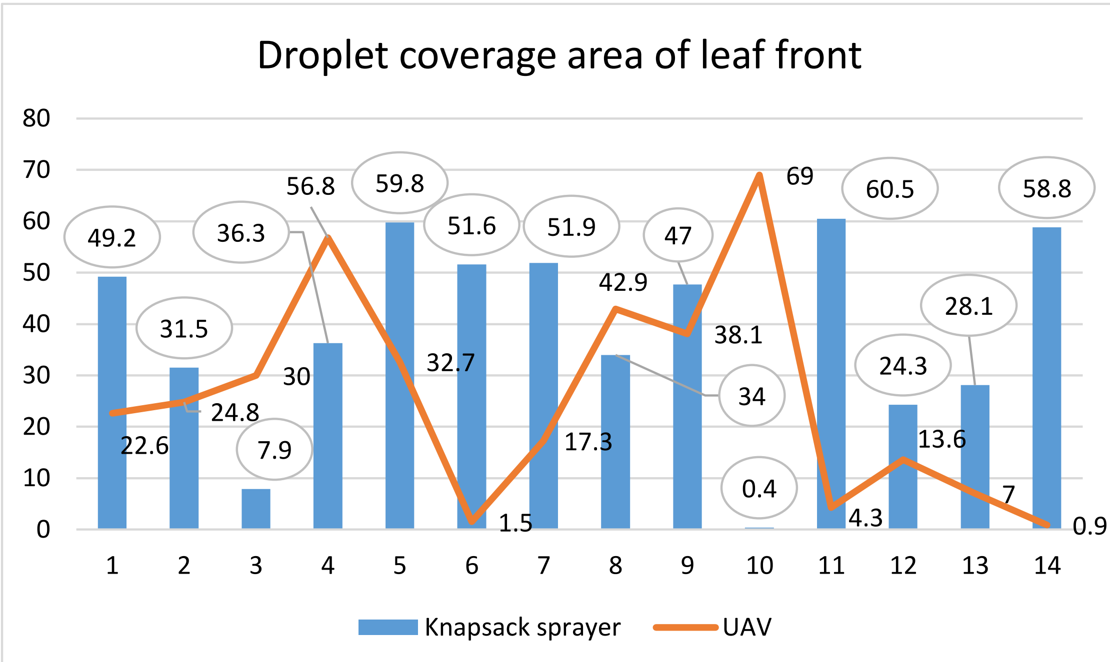

Figure 14: Droplet coverage of leaf front

The effect of UAV sprayers on the droplet coverage in garland chrysanthemum plants is shown in Figure 14 and Table 4. The droplet coverage rate spraying with the knapsack sprayer was significantly higher than that of the UAV sprayer (38.7% versus 25.8%. This is because the spraying volume of the knapsack sprayer (1000 L/ha) was50 times that of the UAV sprayer (20 L/ha). This shows that the amount of spray has a significant impact on the coverage of pesticide droplets, and the coverage of pesticide droplets is positively correlated with the amount of spray. However, in t test, p-value 0.09 > 0.05(p < 0.05) was not considered a significant difference between the two groups.

Table 4: Droplet coverage area on leaf front-t test

Sprayer	Coverage Area %	Number of observations	Minimum	Maximum	Std. dev.	*C V*	*P -value*
Knapsack sprayer	38.7	14	0.4	60.5	18.9	0.49	0.09
UAV	25.8	14	0.9	69.0	20.7	0.80	

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When spraying the leaves of crops for the first time, comparing the droplet coverage of the two spraying equipment, the droplet coverage of the UAV is 25.8%, which is lower than the 38.7% of the knapsack sprayer. The result is the same as the results presented by Shan et al. (2021), who claimed that "the percentage of spray coverage of droplets varies from different spray volumes and droplet sizes"[17]. That is, when the field area is the same and the amount of spray is small, the droplet size will decrease, and the spray coverage will also decrease.

4.2.2 Droplet coverage on leaf back

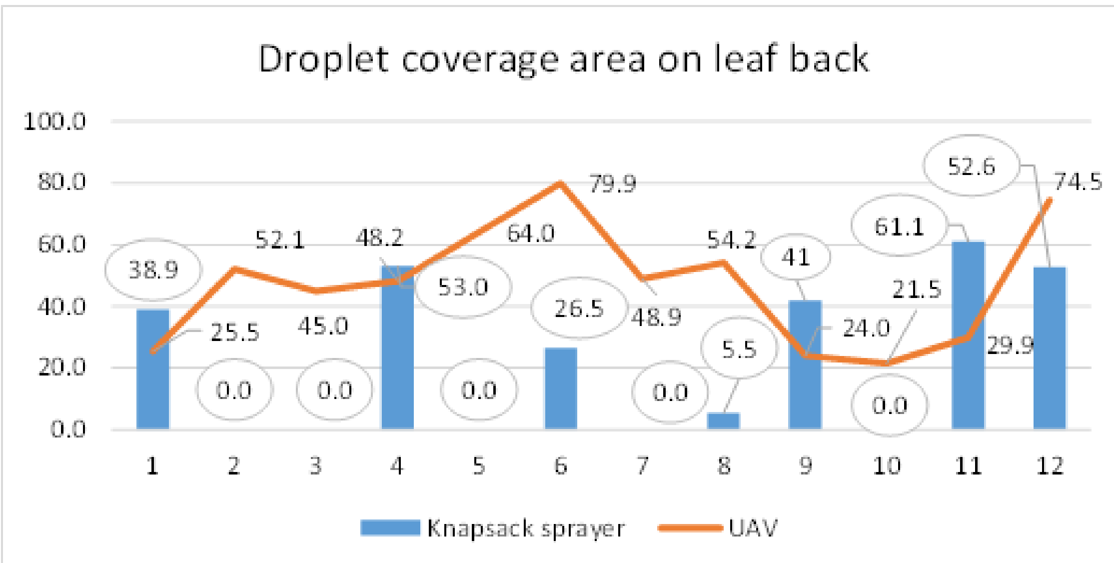

Figure 15: The droplet coverage area on leaf back

In the second spraying, the average droplet coverage of the two groups of sprayers, UAV was 47.3/cm2, knapsack sprayer was 23.3/cm2 (Figure 15and Table 5), which was 2.03 times that of knapsack sprayer, the average droplet coverage of UAV was better. Moreover, in t test, p-value 0.015< 0.05($p < 0.05$) was considered a significant difference between the two groups. The coefficient of variation (CV 1.07>0.41) of the knapsack sprayer was bigger, means it had a worse uniformity in the second spraying operation.

Table 5: Droplet coverage area on leaf back-t test

Sprayer	Coverage area %	Number of observations	Minimum	Maximum	Std. dev.	*C V*	*P -value*
Knapsack sprayer	23.3	12	0	21.5	24.9	1.07	0.015
UAV	47.3	12	61.1	79.9	19.4	0.41	

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In the second spraying on the back of the crop leaves, the droplet coverage rate of the UAV was 47.3%, which was higher than that of the knapsack sprayer (23.3%). The droplet coverage of the knapsack sprayer is relatively small, which is because when spraying on the back of the leaves, the UAV used the downwash airflow of the propeller, it easily turned the back of the leaves and obtained a larger coverage area, but the knapsack sprayer did not have this function.

4.2.3 Discussion of droplet coverage

When it comes to droplet coverage on crop leaves, a larger spraying volume per unit area means less sprayed liquid is required. However, as the coverage decreases, the amount of sprayed liquid also decreases accordingly. That is, when the spraying area of the UAV is the same as that of the knapsack, the spray volume will be less (Knapsack sprayer:1000L/ha; UAV: 20L /ha), the coverage decreases accordingly., the droplet size will be reduced, and the spray coverage will also be reduced. Therefore, in general, the droplet coverage of knapsack spraying will be larger than that of UAV.

4.3 Droplet Average Diameter

4.3.1 Droplet average diameter of leaf front

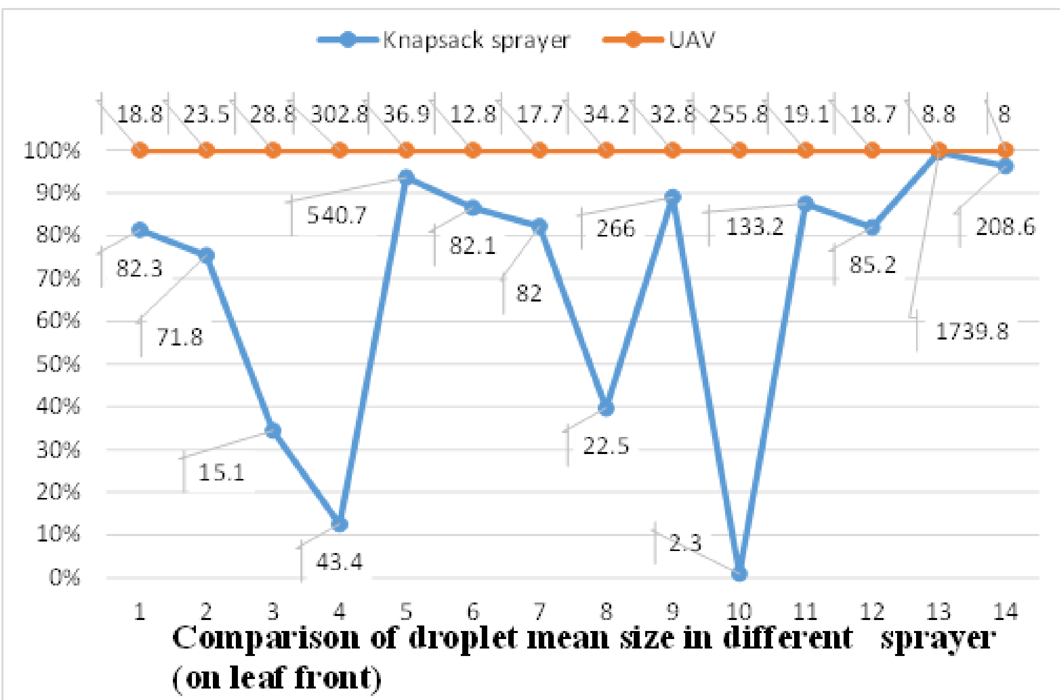

Figure 16: The Comparison of droplet average diameter on leaf front

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In the first spraying operation, the average droplet diameter of the two groups of sprayers were presented in Figure 16 and Table6, UAV was 58.5μm, knapsack sprayer was 241.1μm. According to the American Society of Agricultural Biological Engineers (ASABE S572) droplet size classification standard, the droplet of UAV spraying should be classified as "Very Fine", while that of knapsack sprayer should be classified as "Medium"(Figure 19) . In t test, *p-value 0.162*> 0.05 ($p < 0.05$) was not considered a significant difference between the two groups. Both coefficients of variation are greater than 60%, which means they are either too thin or too thick.

Table 6: Average droplet diameter on leaf front-t test

Sprayer	Droplet mean size(μm)	Number of observations	Minimum	Maximum	Std. dev.	*C V*	*P -value*
Knapsack sprayer	241.1	14	2.3	1739.8	453.4	1.88	0.162
UAV	58.5	14	8	302.8	94.4	1.61	

Classification category	Symbol	Color Code	Approximate Volume Median Diameter (VMD)
Very Fine	VF	Red	<100
Fine	F	Orange	100-175
Medium	M	Yellow	175-250
Coarse	C	Blue	250-375
Very Coarse	VC	Green	375-450
Extremely Coarse	XC	White	> 450

Figure 17: The American Society of Agricultural Biological Engineers (ASABE S572) Droplet sizes are usually expressed in microns (μm).

4.3.2 Droplet average diameter of leaf back

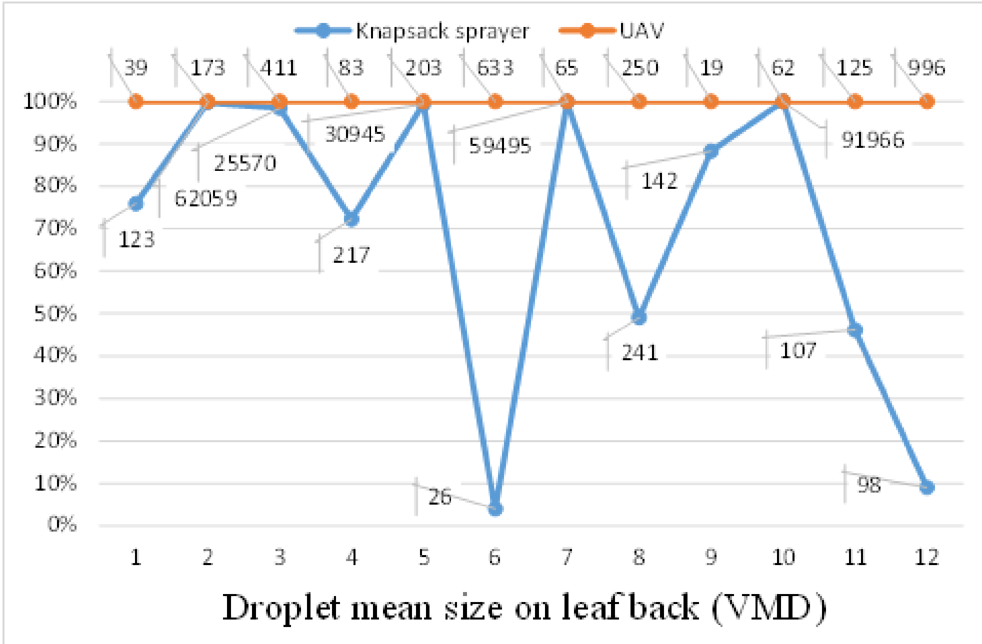

Figure 18: The comparison of droplet average diameter on leaf back

In the second spraying, the droplet average diameter of the two groups of sprayers were presented in Figure 18 and Table 7. UAV was 255µm, knapsack sprayer was 22582µm, this showed that the droplet of UAV spraying was "Coarse", while that of knapsack sprayer was "Extremely coarse". However, in t test, p-value 0.035< 0.05($p < 0.05$) was considered a significant difference between the two groups. Both coefficients of variation are greater than 60%, which means they all had bad uniformity of the droplets.

Table 7: Knapsack sprayer and UAV sprayer on droplet average diameter - t test

Sprayer	Droplet average diameter(µm)	Number of observations	Minimum	Maximum	Std. dev.	*C V*	*P -value*
Knapsack sprayer	22582	12	26.2	91966	32108.8	1.42	0.035
UAV	255	12	18.9	995.8	293.4	1.15	

As shown in the above parameters, when spraying on the back of the crops, the average diameter of the droplets of the UAV was 255µm, which was smaller than the 22582µm of the knapsack sprayer. Based on the principle that the smaller the diameter of the droplet, the better the performance. Therefore, the performance of the UAV was better.

4.3.3 Discussion of droplet average diameter

The mean droplet size was smaller in UAV based sprayer, this could be because of using ultra-

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low volume (ULV) spray nozzles[18].When spraying on the leaf front of crops, the smaller the liquid droplet, the easier it is to evenly cover the plant surface and give full play to the efficacy of the medicine, but it is also easy to drift. Relatively, the larger the liquid droplet are, the less likely it was to evenly cover the plant surface and affect the efficacy of the medicine, but it is not easy to drift. When spraying on the back of the crops, the droplet coverage rate in the independent sample t test, the test statistical probability value p value was 0.035, reaching a significant level of α=0.05, which means that there is a significant difference between the average of the Knapsack sprayer and UAV groups, That is to say, UAV spraying was better than backpack type in terms of droplet diameter. In this experiment, the super large droplets of 22582μm produced by the knapsack sprayer should be caused by the sprayer not being able to spray the pesticide at the back of the leaves at an appropriate angle. After forming a large droplet, it drips directly to the ground, causing the distribution efficiency to decrease and affecting the efficacy of the pesticide.

4.4 Droplet Density

4.4.1 Droplet density of leaf front

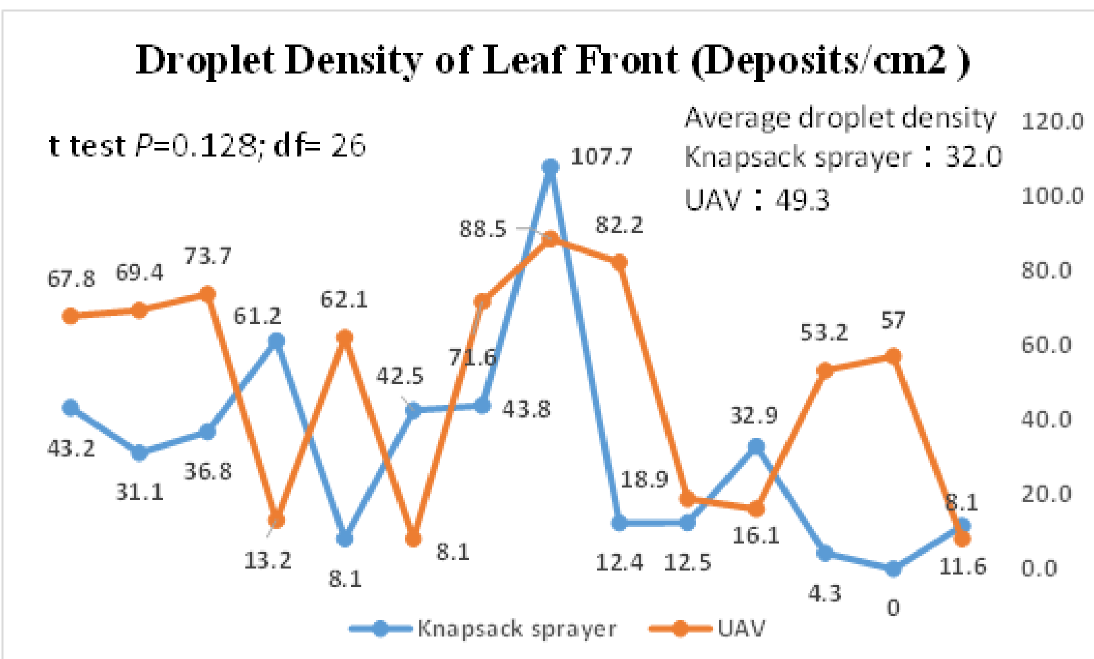

Figure 19: The comparison of droplet density on leaf front

In the first spraying operation, the average droplet density of the two groups of sprayers, UAV was 49.3/cm2, knapsack sprayer was 32/cm2 (Figure 19and Table 8), which is 1.54times that of knapsack sprayer, the average droplet density of UAV was better. However, in t test, *p-value 0.128*> 0.05($p < 0.05$) was not considered a significant difference between the two groups. The coefficient of variation (*CV* 0.89>0.60) of the knapsack sprayer was bigger, means it had a worse uniformity in the first treatment.

Table 8: Knapsack sprayer and UAV sprayer on droplet density - t test

Sprayer	Droplet density(/cm2)	Number of observations	Minimum	Maximum	Std. dev.	*C V*	*P -value*
Knapsack sprayer	32	14	0	107.7	28.5	0.89	0.128
UAV	49.3	14	8.1	88.5	29.6	0.60	

4.4.2 Droplet density of leaf back

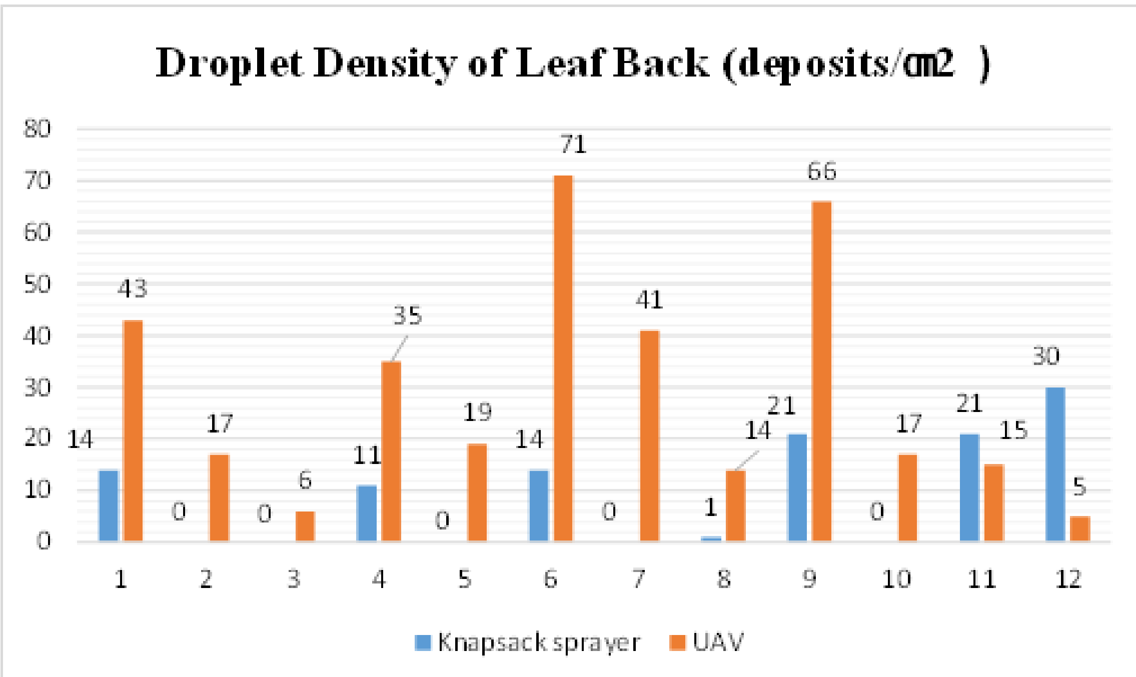

Figure 20: The Droplet density of leaf back

In the second treatment, the average droplet density of the two groups of sprayers, UAV was 29.1/cm2, knapsack sprayer was 9.3/cm2 (Figure 20 and Table 9), which was 3.1 times that of knapsack sprayer, the average droplet density of UAV was better. Moreover, in t test, p-value 0.013< 0.05($p < 0.05$) had significant difference between the two groups. The coefficient of variation (CV 1.14 > 0.76) of the knapsack sprayer was bigger, means it had a worse uniformity in the second treatment.

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Table 9: Knapsack sprayer and UAV sprayer of droplet density - t test

Sprayer	Droplet density(/cm2)	Number of observations	Minimum	Maximum	Std. dev.	*C V*	*P -value*
Knapsack sprayer	9.3	12	0	5	10.7	1.14	0.013
UAV	29.1	12	30	71	22.2	0.76	

4.4.3 Discussion of droplet density

In terms of the two spraying, the results of the research showed that the droplet coverage density of these two sprayers can achieve the ideal spraying effect. In line with the Swiss Syngenta company standard, the density 20-30/cm2 is suitable for insect removal, and the density 50-70/cm2 is suitable for sterilization[19]. However, UAV has a higher coverage density of droplet than knapsack sprayer, which is the same as the research results of Yuan and Wang (2015)

In addition, droplet density related to the effectiveness of pest control had also been proposed by several researchers. Qi Lijun and Fu Zetian (1998) proposed "After the droplet size is determined, different droplet densities determine the amount of pesticide used"[20]. Yuan Huizhuet. Al (2015) claimed "Even high concentrations of pesticides required a certain droplet density at low droplet density".

There is also an interactive relationship between droplet density and other droplet parameters. That is, as the size of droplets decreases, the number of droplets will increase, and the increase in the number of droplets, the coverage density will increase also.

4.5 Control Effect of Pest

Setting up sticky insect paper before and after spraying pesticides to observe the effect of insect control. For the steps of pest control, first of all, 2023.02.08 laid out the sticky insect paper in the field, and from 2023.02.08 to 2023.02.13, the pests on the sticky insect paper were found, there were 15 in area A, 12 in area B, and 27 in total in the second area of A and B .2023.02.13 Spray pesticides on Zone A and B respectively with knapsack sprinklers and drones. After spraying with 10% Chlorfenapyr, 75% Cyromazine and Bacillus thuringiensis subsp. for 10 days, then spray in the field on 2023.02.13 arrange sticky insect paper. On February 22, 2023, it was found that there were 4 pests left on the sticky insect paper in area A, 2 pests left on the sticky insect paper in area B, and a total of 6 pests remained in the second area of A and B. The control effect on pests, the knapsack sprayer 73% and 83% for UAV, the spraying effect of UAV is better than that of knapsack sprayer. The control effect on pests is shown in the attached Table 10 and Figure 21-23.

Table 10: The control efficacy of pest by Knapsack sprayer and UAV

Spraying Date	Treatment	Before spraying	After spraying	Reduction	Control efficacy
13 Feb 2023	Knapsack sprayer	15	4	11	73.3%
	UAV	12	2	10	83.3%

1.2023.02.08 Arrange sticky insect paper.

Figure 21: Arrange sticky insect paper

2.2023.02.08-02.13 The situation of insect pests captured by sticky insect paper before spraying: 15 in area A, 12 in area B, 27 in total.

Figure 22: Before spraying

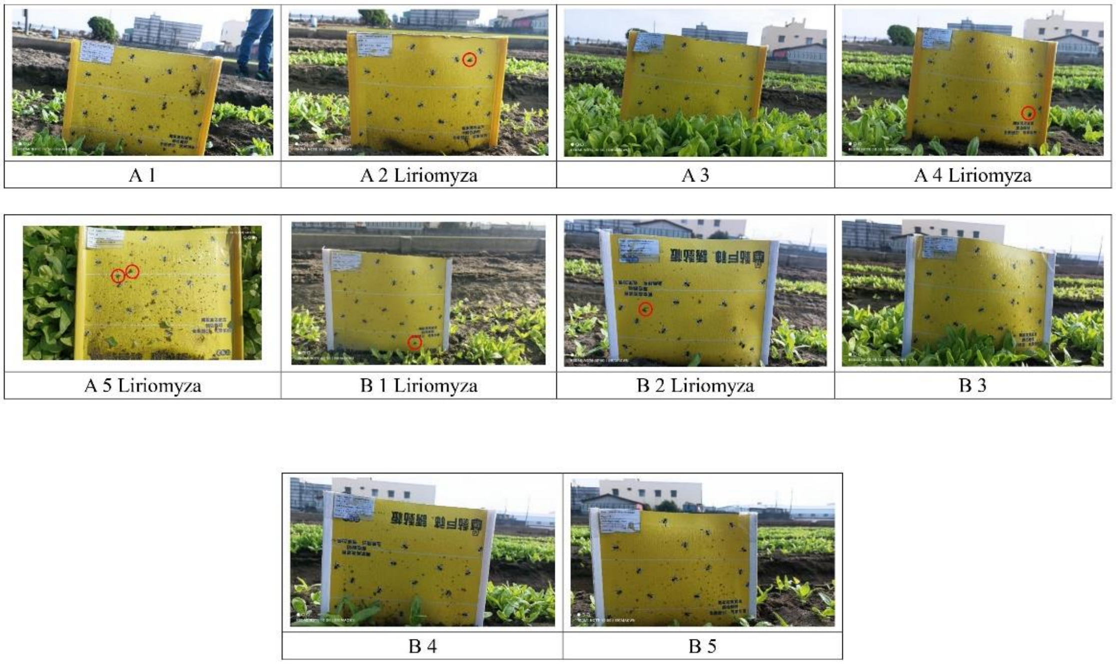

Figure 23: check the sticky insect paper after spraying

4.6 Droplet Drift Test

In this study, on the morning of January 30, 2023, when the UAV was used to spray liquid fertilizer in the field for the first time, the weather was sunny, the temperature was 18 degrees, the wind direction was north-north-west, the wind speed was 3.2m/s, and the flying height was 1.5 meters.

Table 11: The parameter of droplets drift in neighbor field

Distance(m)	Number of Droplets	Total Area	Average Size(μm)	%Area
1	8	3283.5	410.4	1.0
3	241	74087.8	307.4	3.7
5	420	5018.8	11.9	1.7
7	757	7804.9	10.3	2.6
10	346	2363.7	6.8	0.8
15	213	508.4	2.4	0.2

The measured parameters of pesticide droplets drifting to the right adjacent field are shown in the table11.

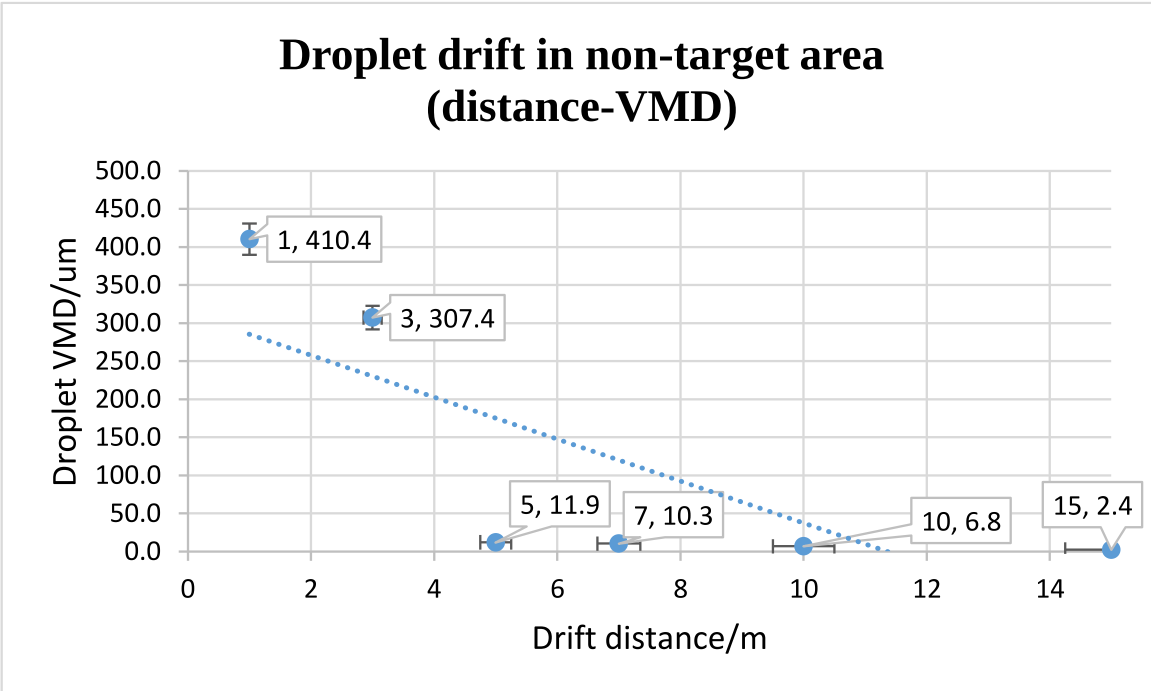

Figure 24: Droplets drift in non-target area (distance-VMD)

In terms of the degree of dispersion of droplet at different distances, the average droplet size at 1 meter away from the farmland boundary was 410.4 μm, at 7 meters it was 10.34 μm,and at 15 meters it was 2.4 μm (Figure 24).This result showed that the smaller the droplet size of the liquid medicine, the farther its drifting distance will be[21].

The above showed that under such weather conditions and flight altitudes, the pesticide droplets were obviously scattered to the adjacent field on the right, which may affect the growth of crops in the adjacent field or cause phytotoxicity to other sensitive areas.

5. CONCLUSION AND SUGGESTION

5.1 Conclusion

In this experiment, two groups of spraying equipment, knapsack and UAV, were used to compare the effects of pesticide spraying from the front and back of Garland Chrysanthemum leaves. The conclusions of droplet number, droplet coverage, droplet size, droplet density, and the impact of

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pesticide spraying on plant diseases and insect pests were made, and the risk concern of droplet drift was also mentioned as follows:

5.1.1 Effect evaluation on droplet deposition

5.1.1.1 Leaf front.

According to the evaluation of droplet deposition parameters (Table12), the number of droplets B (UAV) was better than A (Knapsack Sprayer), the droplet coverage area A was better than B, the droplet volume median diameter B was better than A, and the droplet density B was better than A. Overall, the droplet deposition effect of UAV performed better.

Table 12: Comparison of various parameters of droplet deposition on leaves front

Parameters	A Knapsack Sprayer DW-1600 DAIWA	B UAV XR11001VS	Evaluation of better effect
Average number of droplets	1081	1663	UAV
Coverage rate (%)	38.7	25.8	Knapsack Sprayer
Average droplet diameter (μm)	241.1	58.5	UAV
Droplet density (number of droplets /per cm2)	32	49	UAV

5.1.1.2 Leaf back.

According to the evaluation of the average number of droplet deposition parameters (Table13), B (UAV) was better than A (Knapsack Sprayer) in terms of the number of droplets, the area covered by droplets, the diameter of droplets, and the density of droplets. Overall, the droplets sprayed by UAV on the back of leaves, which deposition effect was better.

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Table 13: Comparison of various parameters of droplet deposition on leaves back

Parameters	A Knapsack Sprayer DW-1600 DAIWA	B UAV XR11001VS	Evaluation of better effect
Average number of droplets	174.3	546.7	UAV
Coverage rate (%)	23.3	47.3	UAV
Average droplet diameter (μm)	22582.2	254.9	UAV
Droplet density (number of droplets /per cm2)	9.3	29.1	UAV

Judging from the droplet deposition results of the two spraying, the number of droplets of the UAV was more than that of the knapsack sprayer; the coverage of the knapsack spraying on the leaf front is better, but the coverage of spraying on the back of the leaves was poor. The evaluation of this item is generally equal; the droplet diameter of the UAV was smaller than that of the knapsack sprayer, and the spraying effect was better; the coverage density of the droplets sprayed by the UAV was higher than that of the knapsack sprayer. Therefore, UAV performed better on the overall effect evaluation.

5.1.2 Pest control effect

In this study, the pest control effect was evaluated by the mortality of pests before and after spraying, so there should be doubts about oversimplification. Qi Lijun and Fu Zetian (1998) proposed that "the pest control effect is that the required droplet density depends on the density, fluidity, properties of the active ingredients in the liquid and their distribution on the target". Among them, how to properly adjust the amount of liquid pesticide and the density of droplets to increase the effect of pest control is worthy of further study.

There are many factors affecting the pesticide application effect, but the droplet distribution structure plays an important role in controlling efficiency. From the results of this experiment, the control effect of UAV spraying on pests and diseases was better, and comparing the optimal parameters of UAV droplet deposition, it could also be obtained that the optimal parameters of droplet deposition have a positive relationship with the control effect of pests and diseases.

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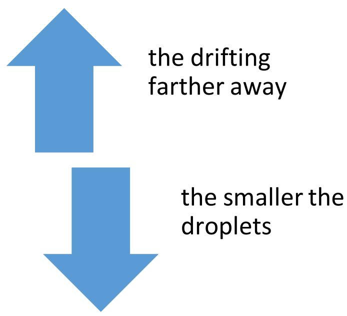
5.1.3 Droplet drift

In the pesticide dispersion test, the smaller the droplet size, the farther the dispersion distance will be, and the greater the wind speed, the further the dispersion will be. Therefore, choosing an appropriate timing for spraying, such as windless, early morning, evening or night, can reduce the degree of mist particle drift.



5.2 Suggestions and Limitations

1. Since this was a comprehensive research involving pesticide deployment, UAV spraying operations, measurement and statistics, etc., it needs to obtain a higher threshold research qualification, for example, the researcher must have the Agricultural UAV Operation Certificate of the Civil Aviation Administration and the pesticide spraying certificate of Inspection and Quarantine Bureau of the Epidemic Prevention (Appendix 7), they take us about eight months to participate in the training to obtain the certificate, so those who want to study the subject of this type, it is recommended to set the research period as one year, so as not to get the certificate when the dissertation is published. The researcher should avoid doubts about the operation qualification, not conducive to the publication of study.
2. In this study, the knapsack sprayer model (DW-1600 DAIWA) was selected, and the results of spraying on the leaves found that although there are 9 in the droplet size (VF has 9), coverage (38.7%), density (32/ cm2) and so on can still meet the droplet classification effect of American Society of Agricultural Bioengineers (<100μm, VF) and the standard range set by Swiss Syngenta and other institutions (density 20-30/cm2 is suitable for insect removal, density 50-70 /cm2 is suitable for sterilization), but because the sprayer does not have relevant performance verification report data, it is impossible to know in advance the range of droplet size under which the nozzle can produce droplets, which is easy for researchers to produce, spraying with backpack sprayers and UAV It is also difficult to correct the human error of the operator compared to the doubts about the unequal effect, so it is recommended that those who are interested in researching such

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subjects choose a sprayer with a performance verification report.

3. The deposition structure of pesticide droplets and the control effect on pests and diseases are affected by the comprehensive factors of pesticide droplet diameter, droplet density and pesticide concentration Therefore, in addition to mastering the optimization parameters of the droplet deposition structure, it is also necessary to have a correct understanding of the pesticide formulation and application method of the target pests and diseases.
4. When carrying out the spraying test in the field, attention must be paid to the climatic conditions. For example, when the wind speed exceeds the second level (3.3m/s) of the Beaufort wind scale, it is easy to cause the spray from the upper wind area to drift to the lower wind area and cause heavy spraying, resulting in spraying The data is distorted; in addition, when the weather conditions such as wind direction and wind speed are not good, the operation should be stopped, so as not to affect the growth of crops in adjacent fields or cause phytotoxicity to other sensitive areas due to the drift of fog particles.
5. There are still many factors that affect the control effect of pests and diseases, including the density, fluidity, concentration of pesticide solution and distribution on crops. This study only evaluates the effect by the number of deaths of pests and diseases before and after spraying, and the research depth is still insufficient. In the future, research can be conducted on the combination of drug concentration and droplet density to enhance the control effect.

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