Drift and deposition of ultra-low altitude and low volume application in paddy field

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Abstract: Field trials were performed to evaluate various techniques for measuring spray deposition and aerial drift during spray application to paddy field. The application of a spraying agent containing the fluorescent dye Rhodamine-B was applied by an unmanned aerial vehicle (UAV) which flew at a height of 5 m, a speed of 3 m/s, and the wind speed of 3 m/s. The results showed that because the downdraft produced by a helicopter rotor increased the penetrability of crops, there is a higher deposition on the upper layer and the under layer than the traditional spraying. The average deposition on the upper layer accounts for 28% of the total spraying, the deposition on the under layer accounts for 26% of the total spraying. The deposition on the under layer takes up 92.8% of the deposition on the upper layer. Droplets drift data showed that the drift of non-target area took up 12.9% of the total liquid spray. The 90% drifting droplets were located within a range of 8 m of the target area; the drift quantity was almost zero at a distance of 50 m away from the treated area.

Keywords: paddy field, ultra-low altitude, low volume, UAV, droplet drift, deposition
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1 Introduction

Agricultural machinery is an important content of agricultural modernization. Since the mid-19th century, men began to widely use animal traction of simple agricultural machinery in agricultural production in Europe and the United States. In the early 20th century, men began to use the tractor of internal combustion engine power which gradually replaced livestock-power agricultural machinery. In the 1920s, the United States began to use aerial application of pesticide, which created a history of agricultural aviation[1].

Rice is the major grain crop in China. It accounts for about 42.2% of national cereal production, 35.2% of the total grain sowing area, and about 34% of insect pest control area over the years, which is one-third of the total control amount. For a long time, the rice disease prevention and control mainly relied on the human-carrying motorized sprayer which was labor-intensive, poor in quality and low in efficiency. Aerial spraying operation can control severe diseases and insect pests over a large area quickly and effectively, and it is an effective way to solve the special field operating condition of the rice fields[2,3]. However, for a long time, the application of large-scale agricultural aircraft developed slowly due to the poor economic and

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low-flying control. Compared with manned aircraft, the advantages of light unmanned aircraft are obvious: ① by the spraying at very low altitude fly, it avoids the problem of aircraft flight control; ② without special takeoff and landing at airport, it has good mobility; ③ the weight is light and cost is low. Therefore, in recent years, people have started to pay attention to using unmanned helicopters in agriculture. At the same time, according to the land management mode in China, such as the status quo that rice mainly grow in the small area of slope fields or terraces, the high adaptability of unmanned spraying aircraft has good market potential and industrial prospect.

At present, there are many reports about pesticide spray quality research conducted by researchers from China and other countries, which can provide a very useful basis for the transformation of spray components[4-7]. Aviation spraying methods have been reported both in China and in international journals, such as the method developed by Franz[8], who used the fluorescence spectrometry to quantify the deposition by analyzing the picture of plant leaves and leaves light-sensitive test paper, and determined the droplet deposition impact of the plant canopy cover characteristics and climatic parameters on cotton, cantaloupe, leafy plants in aircraft spray conditions. Ru et al.[9] studied on the air electrostatic spray and measured deposition with carbon paper and determined drift by eosin staining. Lan et al.[10] at USDA Southern Research Center collected droplet deposition in the cotton canopy, wind drift by water-sensitive paper and mylar cards in the research of fixed-wing aircraft spray. The water-sensitive paper and mylar cards was marked and collected after dried. They read and analyzed the water-sensitive paper with droplet analytical instruments, and analyzed the mylar cards with fluorescence spectrometry. It was used to calculate the deposition, droplet size, droplet coverage, total droplet number, drift distance, additive concentration, and spray height correlation. The results of the research contributed to the selection of appropriate anti-drift additives for aerial spraying, and facilitated aircraft spraying to meet the standards of aviation drift. Fritz et al.[10-13] took this method to carry out aerial spray drift and ground equipment spray drift comparison test for the research of spray drift control technology.

Based on the situation that spray distribution research of unmanned helicopter in paddy crops has not been reported, the current research did a UAV spray droplets deposition and drift law test to provide s theoretical basis and data support to the spray drift control and the development of aviation spray standards.

2 Materials and methods

2.1 Location and spray environmental conditions

This experiment was implemented in the rice fields of Xiongfeng Village, Lili County, Wujiang Town, Suzhou City, Jiangsu Province, China. It was one of the designated test areas of China's National 863 Project. The plots were planned as a rectangular land, with no buildings or trees around. Spray in the same conditions for both the control area and the treated area would not affect spray drift and deposition. The spray solution was pesticide mixed with fluorescence tracer (Rhodamine-B, Shanghai Huachen Co., Ltd.). The collector was polyester cards and polyester fibers according to ISO22866 standard. Zhou and Xue[14,15] used the electric centrifugal nozzle in the research of the UAV aerial spray optimum operating parameters, and determined the spray height, flow rate, diameters of droplet size, nozzle settings and crop characteristics that are summarized in Table 1.

Table 1 Application: sprayer settings and crop characteristics

Nozzle type	Rotary atomizer
Droplet size	296.29 μm
Working width (two nozzles)	7 m above canopy
Flow rate (one nozzle)	850 mL/min
Spray equipment	Z-3 UAV
Tank capacity	20 L
Working width	21 m in total; divided into 3sections of 7 m each
Driving speed	10.8 km h^{-1}
Spray volume	15 $L \cdot ha^{-1}$
Rh-B concentration	2 $g \cdot L^{-1}$
Crop type	rice paddies-Wugengyu 23
Plant age	Mid-tilling stage of crop growth
Soil coverage	90-100%
Crop height	0.65-0.70 m
Leaf Area Index	7.05 $m^2 \cdot m^{-2}$

We used the digital temperature and humidity indicator (Wanyitong Instrument-meter Inc., Shenzhen, Guangdong), China to record the temperature and humidity from 1.0 m and 2.0 m above the crops every 60 seconds. And we used the wind speed measuring instrument 8901 (Wanyitong Instrument-meter Inc., Shenzhen, Guangdong, China) to record the wind speed from 1.0 m, 2.0 m, and 5.0 m above the crops and the wind direction from 2.5 m above the crops every 60 seconds.

2.2 Sampling methods

Figure 1 shows how the sampling collectors and deposition and drift collectors were arranged at the spray area. The sampling collector consists of polyester card (ϕ = 90 mm) and polyester fiber (ϕ = 1 mm). The direction of aircraft was perpendicular to the wind direction. The deposition collectors were arranged along the direction of flight, and the drift collectors were arranged along the direction of wind. In order to make the pesticide spray more stable, the aircraft took off and was hovering 20 m from the spray area, and stopped spraying 10 m away. The flight height (above the crop surface) was 5 m. We measured the droplet deposition on the rice in the spray area and the droplets drift volume in the drift area. In the spray area, the rice sampling points were arranged into a matrix of 5×3 and divided into two layers (Figure 2).

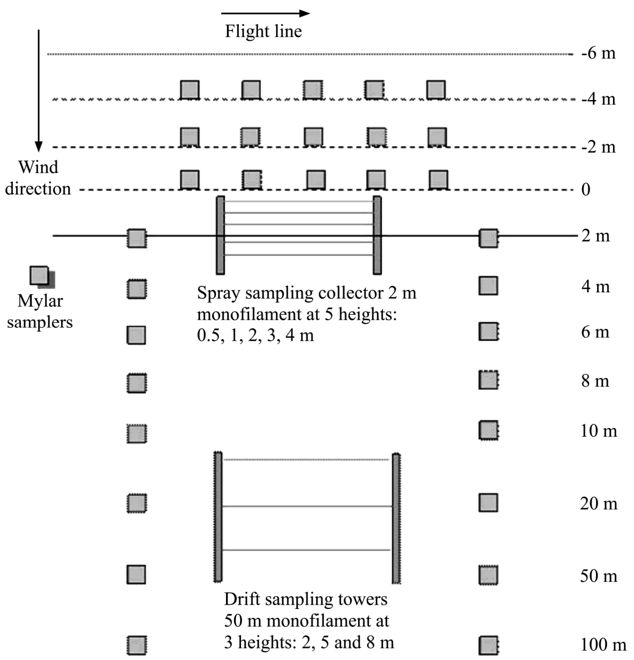

Figure 1 Layout of field sampling locations for aerial drift studies

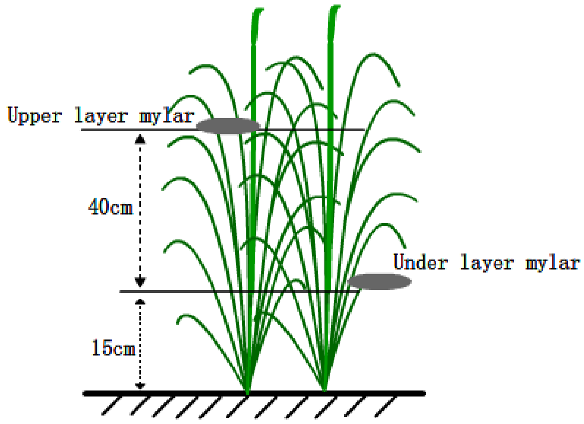

Figure 2 Sketches of sampling collectors

The interval of lateral sampling points and the interval of vertical sampling points were 2 m. In the drift area, the collector was arranged 2 m, 4 m, 6 m, 8 m, 10 m, 20 m, 50 m, and 100 m away from the spray area, in order to collect the droplet drift on the ground. We placed a trestle 2 m away from the spray area, and arranged monofilament fibers at 0.5 m, 1 m, 2 m, 3 m, and 4 m of the trestle. We placed another trestle at a distance of 50 m away from the spray area, and arranged monofilament fibers at 2 m, 5 m, and 8 m of the trestle, in order to receive the drift of the droplets in the air.

After the droplets on the collector were drying in each trestle, we wore disposable gloves to collect the polyester cards and monofilament fiber. Then we marked them, putted them in Ziploc bags, placed them in coolers, and took them back to the laboratory for analysis. We used deionized water to elute the Rhodamine-B on the film of each collector, and used the fluorescence spectrophotometer (F95) to determinate the fluorescence of each eluent. The deposition of Rhodamine-B in the eluent could be calculated according to the “concentration – fluorescence” standard curve of the Rhodamine-B standard. Liquid deposition on a unit area could be determined precisely.

The formula of deposition is

$$\beta_{dep} = \frac{(\rho_{smpl} - \rho_{blk}) \times F_{cal} \times V_{dii}}{\rho_{spray} \times A_{col}}$$

$$\beta_{dep\%} = \frac{\beta_{dep} \times 10000}{\beta_v}$$

where, β_{dep} is the spray drift deposit, expressed in microliters per square centimeter r (μL/cm^2); $\beta_{dep\%}$ is the spray drift percentage (%); β_v is the spray volume, expressed in liters per hectare (l/ha) ; β_{smpl} is the fluorimeter reading of the sample; ρ_{blk} is the fluorimeter reading of the blanks (collector + dilution water); F_{cal} is the calibration factor; V_{dii} is the volume of dilution liquid used to dilute tracer from collector, expressed in liters (l); ρ_{spray} is the spray concentration, or amount of tracer solute in the spray liquid sampled at the nozzle, expressed in grams per liter (g/l); A_{col} is the projected area of the collector for catching the spray drift, expressed in square centimeters (cm^2).

3 Results and analysis

3.1 Environment

The average air temperature and wind speed of the test is shown in Table 2.

Table 2 Wind speed and air temperature averaged over a minute during the measurement arrays

Measured quantity	Wind speed/m·s^{-1}			Air temperature/℃	
Height of measurement	1.0 m	2.0 m	5.0 m	1.0 m	2.0 m
Field conditions	2.2±0.5	3.3±0.8	4.3±0.7	28.3±0.6	29.3±0.5

Figure 3 shows that the wind speed increased with height, and the phenomenon was fitted with an exponential curve. Therefore, wind speed can be calculated from one height to another. We can take measurements on spray drift pertinently by setting different sampling heights at longer distance. Experiments were carried out at a relatively humidity of 55%±10% and a vapour pressure deficit (v.p.d.) of 37.8±6.3 mbar. In the process of spraying pesticides, the air humidity could not be too high (such as just under the rain), otherwise the droplet would fall from the leaf surface easily; and if it was too low (such as the hot noon), droplets would easily evaporate during the falling.

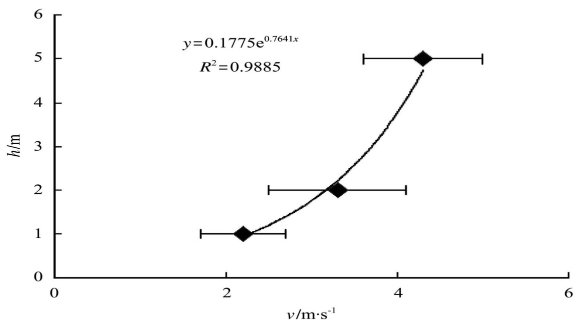

Figure 3 Curve fitting of wind speeds with height

3.2 Spray deposition between different layers of the rice plants

As we can see from the results of analysis, there was no significant difference between droplet deposition of the upper and lower rice plants in the sprayed area. In Figure 4, the dashed line indicates the average percentage of deposition in the upper and lower layers of rice plants.

Because of powerful backspin airflow, rice leaves had high deposition in the upper and lower blades. The average deposition on the upper part took about 28% of total spray volume, and the average deposition on the lower part took about 26% of total spray volume. The deposit volume on the lower part reached 92.8% of the upper part deposition.

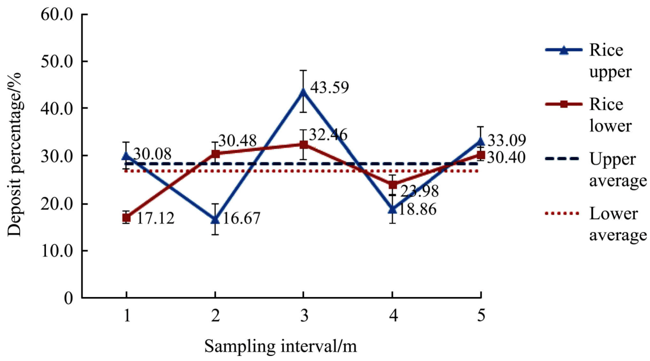

Figure 4 Rice upper and lower deposition (cm^2)

3.3 Determination of spray drift

In the test the flying height was 5 m above the crop top, and the speed was 3 m/s. The wind speed was 4-5 m/s, temperature was 34°C, and the relative humidity was 60%. The spraying area was 1 170 m^2, liquid volume was 1.8 L, and the sampling area was 1 000 cm^2.

The result of Figure 5 shows that: the droplet drift volume accounted for 12.9% of the total spray volume; while 90% of the drift was concentrated within eight meters of the sprayed area. As seen in Figure 6, on the trestle which was two meters away from the spray district, the drift of at 0.5 m height was 14.6%, and the drift of at 4 m height was 4.8%. As the altitude increased, the spray drift decreased by nearly 10%. However, on the trestle which was 50 m away, the droplet drift was almost zero.

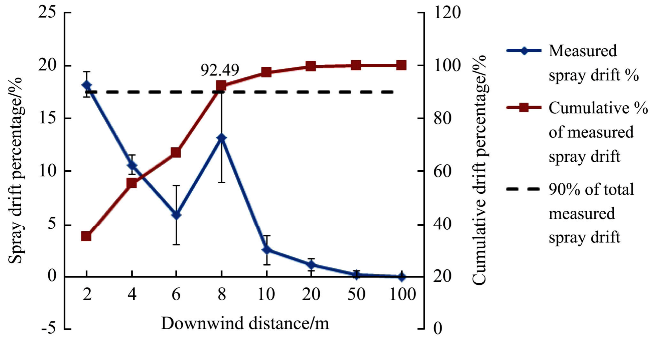

Figure 5 Drift percentage at different distances from spraying area

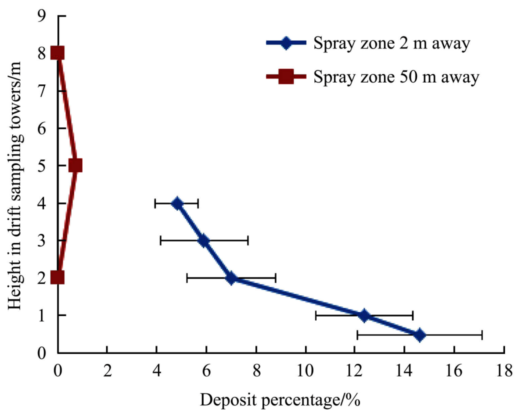

Figure 6 Drift percentage of the different heights deposition at 2 m and 50 m locations in drift area

4 Conclusions

1) We used tracer Rhodamine-B aqueous as spray liquid, and proved by the aircraft low-volume spraying test that all tests could be implemented without any auxiliaries in liquid in the operating environment where relative humidity was no less than 60% and wind speed was less than 5 m/s.

2) Because the propeller can produce a powerful downward air stream, when we use the low altitude helicopter, droplets can penetrate to the lower part of crops, and the liquid deposition of the lower part can reach 92.8% of the upper part, which has great significance in pest control.

3) In the condition that the wind speed is smaller than 5 m/s and the aerial spray height is 5 m, we can control 90% of the drift in 8 m effectively. It provides a reference for the division of buffer strip in spraying.

4) Very little research has been conducted about the basic theory of air spray technology in China up to now. The settlement laws of low-altitude spraying and the operating standards of aviation spraying safety will be the focus.

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