

# Analysis of pesticide use efficiency of a UAV sprayer at different growth stages of rice

Qingqing Zhou, Xinyu Xue\*, Weicai Qin, Chen Chen, Chen Cai

(Nanjing Research Institute for Agricultural Mechanization, Ministry of Agriculture and Rural Affairs, Nanjing 210014, China)

**Abstract:** Pesticide use efficiency is an important index to evaluate the spraying quality of a sprayer. However, the existing sampling methods and calculation results for pesticide use efficiency of crop plants still exist problems such as complex operation and poor repeatability. In this study, the experiment of pesticide use efficiency of a CE-20 UAV sprayer at different flight speeds (3 m/s, 4 m/s, 5 m/s) and nozzle types (F110-015, F110-025) was conducted and analyzed by using polyester card and rice plant sampling method, combined with the plant weight per unit area at different growth stages (tillering stage, jointing stage, booting stage) of rice. The results showed that there was no significant difference between the method of polyester card and the method of plant, which indicated that the method based on plant weight per unit area was reliable. The best operation parameters of the CE-20 UAV sprayer were with 4m/s in flight speed and F110-025 nozzle, and the best plant pesticide use efficiencies are 47.1%, 56.1% and 52.6%, respectively for each growth stage, which are better than those of the 3W-30 engine-driven knapsack sprayer that has a plant pesticide use efficiency of 41.8%, 38.6% and 37.9%, respectively for each growth stage. This study lays a basis for the determination of the best sampling method for pesticide use efficiency, and provides a reference for the optimization of operation parameters of UAV sprayer at different growth periods of rice.

**Keywords:** rice, growth period, UAV sprayer, pesticide use efficiency

**DOI:** 10.33440/ijpaa.20200301.64

**Citation:** Zhou Q Q, Xue X Y, Qin W C, Chen C, Cai C. Analysis of pesticide use efficiency of a UAV sprayer at different growth stages of rice. *Int J Precis Agric Aviat*, 2020; 3(1): 38–42.

## 1 Introduction

Rice is one of the most important cereal crops in China<sup>[1]</sup>. Due to the high temperature and humidity of rice growth environment, diseases and insect pests frequently damage rice in different growth stages. Chemical control is a fast and efficient means of plant protection<sup>[2]</sup>. Pesticide is a valuable resource. With people's attention to environmental issues and food safety, the dosage and application frequency of pesticide application are gradually guided and regulated. Pesticide application technology is an important factor that affects environmental safety, pesticide utilization and control effect<sup>[3]</sup>. Pesticide loss seriously in the traditional runoff spray with large flow rate<sup>[4]</sup>. Backpack sprayer is widely used by farmers in China which has high working intensity, poor distribution quality and high exposure risk. With the advantages of high efficiency, flexibility and separation of human and machine, UAV sprayer has been developed and popularized rapidly<sup>[5]</sup>.

The earlier research of UAV sprayer mainly focuses on the analysis of deposition quality, such as coverage rate and deposition

density, in order to develop the matching operation mode and optimize the operation parameters<sup>[6-8]</sup>. Pesticide use efficiency is an important indicator of deposition quality, which refers to the ratio of the amount of pesticide deposited on the target crop to the total spraying amount. At present, the deposition amount of tracer captured by the artificial sampling card or plant leaves / stems / spike are mainly used to test the pesticide use efficiency. For example, Yuan H Z<sup>[9]</sup> used ponceau and glass slides to test the deposition rate on cucumber leaves and ground loss rate of the knapsack sprayer. Zhu Y K<sup>[10]</sup> used allura red and plastic sheet to study the loss rate of knapsack manual sprayer and knapsack mobile mist sprayer. Jensen<sup>[11]</sup> used BSF tracer to study the ground loss rate of pesticides in different growth stages of wheat. Ellis<sup>[12]</sup> used sodium fluorescein to analyze the effect of different types of additives on the canopy deposition of wheat. Holloway<sup>[13]</sup> used sodium fluorescein to analyze the effect of different types of additives on the coverage and deposition of soybean, pea and wheat leaves. Pergher<sup>[14]</sup> used food stain citric yellow to analyze the deposition and loss rate of different orchard sprayers on grapes. In the research of UAV sprayer deposition, Qin W C used rhodamine B and polyester card to study the deposition of N-3 oil powered single rotor UAV on rice and maize<sup>[15,16]</sup>. He L<sup>[17]</sup> analyzed the effects of additives and application amount on rice canopy deposition of 3WQF120-12 oil powered single rotor UAV sprayer by using allura red and filter paper sampling. Wang G B<sup>[18]</sup> added rhodamine B to study the deposition of 3WQF120-12 oil powered single rotor UAV sprayer on wheat spike and polyester card.

In summary, tracer combined with manual collection card method has been applied and confirmed in pesticide utilization test. However, the actual pesticide deposition of the plant itself is represented by the deposition amount of leaves, spike or fruits, and

**Received date:** 2020-03-07 **Accepted date:** 2020-03-16

**Biographies:** **Qingqing Zhou**, Assistant Research Fellow, research interests: plant protection machinery and application technology research. Email: 912311431@qq.com; **Weicai Qin**, PhD, Associate Research Fellow, research interests: plant protection machinery and spraying quality evaluation. Email: qinweicai@caas.cn; **Chen Chen**, Assistant Research Fellow, research interests: plant protection machinery and application technology research. Email: 3043095@163.com; **Chen Cai**, Assistant Research Fellow, research interests: plant protection machinery and application technology research. Email: 814420600@qq.com.

\***Corresponding author:** **Xinyu Xue**, PhD, Research Fellow, research interests: crop protection and machinery engineering, Email: xuexynj@qq.com.

it is difficult to calculate the pesticide use efficiency of the whole plant according to the local deposition of the plant. In aspect of pesticide use efficiency test of the whole crop, Wang M<sup>[19]</sup> collected rice plants with allura red as indicator, and used the method of plant density to calculate the pesticide use efficiency of several common plant protection machines in different growth periods of rice. However, rice's tillering ability is very strong, the plant size is uniform, and the estimation deviation of plant number is large. According to ISO 24253 standard<sup>[20,21]</sup>, pesticide use efficiency is calculated by deposition amount and leaf area index (LAI). On one hand, deposition of stem or spike is ignored, on the other hand, different measuring instruments have different LAI test results<sup>[22]</sup>. In addition, both the calculation of the number of plants and the test of leaves area increased the workload of complex and repeated field experiments.

In this paper, allura red with strong stability and low residues was used as indicator<sup>[23]</sup>, polyester card and rice plant were used as the sampling methods. The results of paired t-test show that pesticide use efficiency has no difference between the two sampling methods. It can be verified the sampling method and data processing are reasonable. Combined with different growth stages (tillering stage, jointing stage and booting stage) of rice, the influence of pesticide use efficiency of CE-20 UAV sprayer under different flight speeds (3 m/s, 4 m/s, 5 m/s) and different nozzle types (F110-015, F110-025) was analyzed. The operation parameters of UAV sprayer at different growth stages of rice were optimized. This study lays a basis for the determination of the best sampling method for pesticide use efficiency.

## 2 Materials and methods

### 2.1 Test material

Experimental instruments are LAI-2200C canopy analyzer (Beijing ecotek technology Co., Ltd.); Watchdog 2900ET ground meteorological station, with a minimum sampling interval of 1 min (Spectrum company of the United States); 722 N visible light spectrophotometer (Inesa analytical instrument Co., Ltd); Ten-thousandth precision electronic balance, precision 0.0001 g, range 200 g; Electronic scale, precision 0.1 g, range 30 kg. The test materials used are polyester card ( $\Phi$  9 cm), sampling rod, omnidirectional clamp, tape measure (range 20 m), scissors, measuring cylinder, stirring rod, mixing bucket, plastic bag, label paper, light shielding bottle, distilled water, 0.22  $\mu$ m water system filter membrane (Jin Teng Germany PES filter), medical needle tube, allura red (Beijing Solarbio Technology Co., Ltd., purity 85%).

### 2.2 Test fields and crops

The test site is in Wujiang National Modern Agriculture Demonstration Zone, Jiangsu Province, each test plot is about 20m wide and 90 m long. The tested rice variety was japonica rice, which was planted directly in late May. Combined with the diseases and insect pests that need to be controlled, experiments were conducted at the tillering stage on July 30, 2019, jointing stage on August 16, 2019, and booting stage on September 8, 2019 of the rice, respectively. Rice growth period and control targets, LAI of the rice field, wind speed, temperature and humidity, are recorded in Table 1.

**Table 1 Growth period and control targets of rice**

| Growth period   | Time       | Height/cm | LAI  | Control targets                | Pesticide                          | Wind speed/m·s <sup>-1</sup> | Temperature/°C | Humidity/% |
|-----------------|------------|-----------|------|--------------------------------|------------------------------------|------------------------------|----------------|------------|
| Tillering stage | 2019.07.30 | 35~40     | 2.64 | Cnaphalocrocis medinalis, rice | Pymetrozine, cyanidin·mefe-nozide, | 2~4                          | 36~37          | 55~60      |
| Jointing stage  | 2019.08.16 | 50~55     | 4.07 | planthopper, Sheath            | Jinggangmycin,                     | 2~6                          | 30.5~33        | 69~74      |
| Booting stage   | 2019.09.08 | 70~75     | 5.49 | blight, rice blast             | Clomithromycin                     | 3~7                          | 27.8~31        | 62~69      |

### 2.3 Test equipment and operating parameters

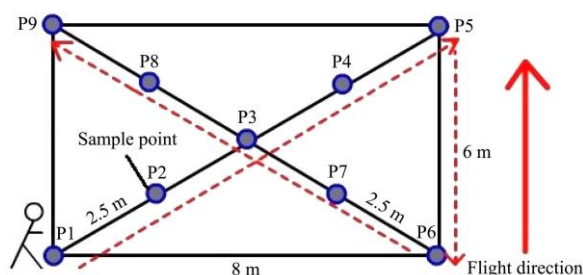
The test equipment was a CE-20 electric single-rotor UAV sprayer (Wuxi Hanhe Aviation Technology Co., Ltd., Jiangsu). Rated load is 20 kg, rotor diameter is 2.4 m, spray bar length is 1.44 m, and nozzle number is 2. RTK and GPS are used for precise positioning. Fixed flight height of 2 m and spray width of 4 m. Change flight speed from 3 m/s to 4 m/s and 5 m/s, change nozzle from Teejet F110-025, spray pressure is 0.3 MPa, to Teejet F110-015, spray pressure is 0.4 MPa, the actual spraying amount of each plot was recorded after spraying. The contrast machine is a 3W-30 engine-driven knapsack sprayer (Huasheng Zhongtian Machinery Group Co., Ltd., Shandong), with a spray width of 7~10 m, and a spraying amount of 150 L/hm<sup>2</sup>. The scheme design of operation parameters is shown in Table 2.

**Table 2 Operation parameter scheme design**

| Model | Spray height/m | Spray width/m | Nozzle, pressure, nozzle level | Speed /m·s <sup>-1</sup> | Spray volume /L·hm <sup>-2</sup> |
|-------|----------------|---------------|--------------------------------|--------------------------|----------------------------------|
| CE-20 | 2              | 4             | F110-015 0.4 MPa<br>Fine       | 3                        | 19.5                             |
|       |                |               |                                | 4                        | 15                               |
|       |                |               |                                | 5                        | 12                               |
|       |                |               | F110-025 0.3 MPa<br>Fine       | 3                        | 27                               |
|       |                |               |                                | 4                        | 21                               |
|       |                |               |                                | 5                        | 16.5                             |
| 3W-30 | /              | 7~10          | /                              | 0.5                      | 150                              |

### 2.4 Pesticide deposition test

Prepare concentration of 5 g/L (for UAV sprayer) and concentration of 2 g/L (for knapsack sprayer) allura red solution. In addition, 5 mL of low capacity spraying additive was added to each liter of spraying liquid to inhibit evaporation, drift and promote sedimentation and adhesion. Take a small amount of original liquid into a shading bottle and bring it back to laboratory for concentration analysis. A rectangular area of 8 m × 6 m was taken in the middle of the test area, as shown in Figure 1. The direction indicated by the red solid line arrow is the flight direction. P1~P9 are sampling points. Polyester cards were placed horizontally at the top and bottom of rice canopy with universal clamp to test the deposition rate and loss rate, as shown in Figure 2. After finished the arrangement of polyester card, stir the rice plants to return them to normal shape.



**Figure 1 Sampling point position diagram**

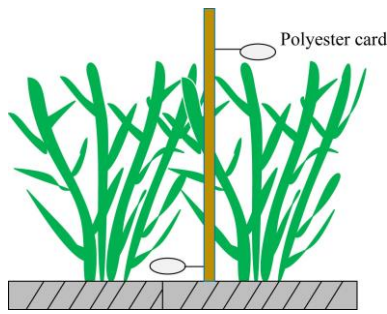


Figure 2 Location of polyester card

After spraying was completed, polyester cards were collected in time. Each polyester card should be put into a plastic bag separately, and recorded the operation parameters, sampling points and position on the label. Collect 10 rice plants around the sampling point (pay attention not to pick plants only in a single hole). Put them into plastic bags and mark them. Rice plants on 900 cm<sup>2</sup> area of 3 blank plots were collected and put them into plastic bags. All samples are sealed, stored in dark and cool place, and brought back to laboratory for analysis in time.

**2.5 Standard curve equation of allura red sample**

A certain concentration of allura red solution was prepared, and the absorbance was measured in a wavelength range from 488 nm to 516 nm. The absorption curve of allura red is shown in Figure 3. It can be seen that the maximum absorption wavelength of the allura red is 502~504 nm, and 502 nm is selected in this test.

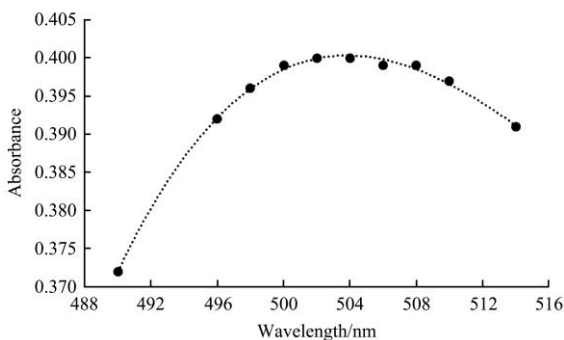


Figure 3 Absorption curve of alluring red

The allura red standard solutions with different concentration gradients from 0 mg/L to 5 mg/L were prepared. The absorbance of standard solutions were tested, and a standard curve equation of the concentration with respect to the absorbance was established, see formula (1).

$$\rho = 20.264A - 0.078 \tag{1}$$

where,  $\rho$  is concentration, mg/L;  $A$  is absorbance difference between standard concentration solution and distilled water.

**2.6 Sample processing**

The weight of blank plots' plants were weighed and recorded. The plant weight per unit area was obtained, which is expressed by  $S_m$ , g/cm<sup>2</sup>, plant weight per unit area of different growth stages are summarized in Table 2.

**Table 2 Plant weight per unit area in each growth period of rice**

| Growth stage    | 900 cm <sup>2</sup> of plant's weight/g |       |       | $S_m$ /g·cm <sup>-2</sup> |
|-----------------|---|-------|-------|---------------------------|
| Tillering stage | 155.1                                   | 179   | 138.4 | 0.175                     |
| Jointing stage  | 201.9                                   | 248.6 | 228.6 | 0.252                     |
| Booting stage   | 451.3                                   | 399   | 375.7 | 0.454                     |

Note:  $S_m$  stands for plant weight per unit area.

Elute polyester card, sample plant and blank plant, the eluent was filtered by syringe with 0.22 μm water-based membrane filter,

and measured by visible light spectrophotometer. Original liquid was diluted, filtered and measured too. The concentration of allura red can be calculated based on the standard curve of concentration-absorbance.

The spray deposition amount per unit area of polyester card is calculated according to formula (2). The spray deposition amount per unit area of rice plant is calculated according to formula (3).

$$\beta_{dep} = \frac{(\rho_{smp} - \rho_{blk}) \times F_{cal} \times V_{dii}}{\rho_{spray} \times A_{col}} \tag{2}$$

$$\beta_{dep} = \frac{(\rho_{smp} - \rho_{blk}) \times F_{cal} \times V_{dii}}{\rho_{spray} \times m / S_m} \tag{3}$$

where,  $\beta_{dep}$  is spray deposition amount per unit area, mL/cm<sup>2</sup>;  $\rho_{smp}$  is sample eluent concentration, mg/L;  $\rho_{blk}$  is blank sample eluent concentration, mg/L;  $F_{cal}$  is calibration coefficient, polyester card is 1, rice test value is 1.034;  $V_{dii}$  is volume of eluent, mL;  $\rho_{spray}$  is concentration of allura red, mg/L;  $A_{col}$  is area of polyester card, cm<sup>2</sup>,  $m$  is weight of collected plant samples, g;  $S_m$  is plant weight per unit area, g/cm<sup>2</sup>.

The pesticide use efficiency is obtained by calculating the ratio between deposition amount per unit area, as shown in formula (4).

$$\beta_{dep\%} = \frac{\beta_{dep} \times 10^5}{\beta_V} \times 100\% \tag{4}$$

where,  $\beta_{dep\%}$  is spray deposition rate, %;  $\beta_{dep}$  is deposition amount per unit area, mL/cm<sup>2</sup>;  $\beta_V$  is and spray amount per unit area, L/hm<sup>2</sup>.

**2.7 Data processing**

Paired t-test was used to test the significant difference between polyester card method and plant method by using SAS statistical analysis software. Multiple comparison method of LSD was used to analyze the influence of the operation parameters in different growth periods on the use efficiency of pesticides, the significant level  $\alpha$  was 0.05.

**3 Results and analysis**

**3.1 Pesticide use efficiency**

Deposition rate of upper polyester card, referred to as UDR. Deposition rate of lower polyester card is the pesticide loss rate, referred to as LR. The difference between the two layers of polyester card deposition is the spray deposition rate, referred to as SDR. Plant pesticide use efficiency, referred to as PPUR. See Table 3 for pesticide deposition of CE-20 UAV sprayer.

**Table 3 Pesticide use efficiency of CE -20 UAV sprayer**

|                 | Nozzle F110- | 015                     | 015  | 015  | 025  | 025  | 025  | mean |
|-----------------|--------------|-------------------------|------|------|------|------|------|------|
|                 |              | Speed/m·s <sup>-1</sup> | 3    | 4    | 5    | 3    | 4    |      |
| Tillering stage | UDR/%        | 45.7                    | 71.6 | 77.4 | 93.1 | 89.2 | 79.3 | 76.1 |
|                 | LR/%         | 25.3                    | 36.7 | 37.5 | 50.6 | 45.6 | 41.2 | 39.5 |
|                 | SDR/%        | 20.4                    | 34.9 | 39.9 | 42.5 | 43.6 | 38.1 | 36.6 |
|                 | PPUR/%       | 27.1                    | 27.1 | 25.8 | 40.3 | 47.1 | 40.3 | 34.6 |
| Jointing stage  | UDR/%        | 75.0                    | 57.5 | 53.9 | 83.5 | 75.0 | 74.8 | 70.0 |
|                 | LR/%         | 20.7                    | 30.5 | 23.8 | 36.7 | 18.0 | 29.6 | 26.6 |
|                 | SDR/%        | 54.3                    | 27   | 30.1 | 46.8 | 57.0 | 45.2 | 43.4 |
|                 | PPUR/%       | 57.3                    | 42.5 | 22.0 | 41.8 | 56.1 | 54.1 | 45.6 |
| Booting stage   | UDR/%        | 49.0                    | 63.1 | 39.4 | 72.7 | 53.6 | 47.1 | 54.2 |
|                 | LR/%         | 11.1                    | 20.1 | 17.0 | 20.5 | 18.1 | 15.2 | 17.0 |
|                 | SDR/%        | 37.9                    | 43.0 | 22.4 | 52.2 | 35.5 | 31.9 | 37.2 |
|                 | PPUR/%       | 36.9                    | 41.1 | 28.5 | 40.9 | 52.6 | 25.9 | 37.7 |

Note: UDR means upper deposition rate, LR means loss rate, SDR means spray deposition rate, PPU means plant pesticide utilization.

The average UDR of CE-20 UAV sprayer in rice tillering stage, jointing stage and booting stage was 76.1%, 70.0% and 54.2%, respectively. UDR is mainly affected by wind speed. According to Table 1, the wind speed on the day of application at the booting stage was above 3 m/s, and the gust was up to 7 m/s. LR was 39.5%, 26.6% and 17.0% in three periods, respectively. LR decreased with the increase of LAI.

**3.2 Comparison of polyester card method and plant method**

Paired t-test was used to test the significant difference between polyester card method and plant method. See Table 4 for t test results of paired samples of SDR and PPUR.

**Table 4 Paired t test results**

| Test statistic | mean  | Std. Deviation | Std. Error Mean | Confidence Interval of the Difference |       | t value | df | Sig.  |
|----------------|-------|----------------|-----------------|---------------------------------------|-------|---------|----|-------|
|                |       |                |                 | Lower                                 | Upper |         |    |       |
| SDR-PPUR       | -0.26 | 8.55           | 2.01            | 6.42                                  | 12.82 | -0.13   | 17 | 0.898 |

Note: SDR means spray deposition rate, PPUR means plant pesticide utilization.

It can be seen from table 4 that the average of difference between SDR and PPUR is -0.26, with a significance of P is 0.898. Accepting the original hypothesis, it is considered that there is no significant difference between the polyester card method and the plant method for testing the pesticide use efficiency, which indicates that the plant pesticide use efficiency test method with plant weight unit area is reliable. In field test, the simple

polyester card method usually used to test the pesticide utilization. However, due to the complexity of the field environment and many influencing factors, it is necessary to arrange enough sampling points ( $\geq 9$ ) to prevent the existence of abnormal points to be eliminated.

**3.3 Effect of operating parameters on PPUR**

Variance analysis method is used to analyze the influence of various factors on the pesticide use efficiency of rice plants. Due to the poor weather conditions on the day of booting stage spraying, only the tillering stage and jointing stage were analyzed, and the results are shown in Table 5. From the analysis of variance table, it can be summarized that nozzle type has a significant impact on PPUR pesticide use efficiency of rice at tillering stage, while flight speed has no significant impact on PPUR.

The influence of each factor on PPUR is shown in Figure 4. PPUR increased with the increase of nozzle type. At tillering stage, PPUR increased first and then decreased with the increase of flight speed, and at jointing stage, PPUR remained stable first and then decreased with the increase of flight speed. When the height is 2 m and the spray width is 4 m of CE-20 UAV sprayer, the optimal operating parameters were with 4m/s flight speed and F110-025 nozzle, and PPUR is 47.1%, 56.1% and 52.6% for tillering stage, jointing stage and booting stage respectively. The PPUR of 3W-30 engine-driven knapsack sprayer is 41.8%, 38.6% and 37.9% respectively for each growth stage.

**Table 5 Variance analysis of PPUR**

| Growth period   | Source | df | Sum of squares | Mean square | F value | P value | Sig.    |
|-----------------|--------|----|----------------|-------------|---------|---------|---------|
| Tillering stage | Nozzle | 1  | 379.2          | 379.2       | 58.2    | 0.017   | *       |
|                 | Speed  | 2  | 18.9           | 9.5         | 1.5     | 0.408   | No sig. |
|                 | Error  | 2  | 13.0           | 6.5         |         |         |         |
|                 | Total  | 5  | 411.2          |             |         |         |         |
| Jointing stage  | Nozzle | 1  | 152.0          | 152.0       | 0.53    | 0.543   | No sig. |
|                 | Speed  | 2  | 172.6          | 86.3        | 0.3     | 0.769   | No sig. |
|                 | Error  | 2  | 233.3          | 116.6       |         |         |         |
|                 | Total  | 5  | 746.1          |             |         |         |         |

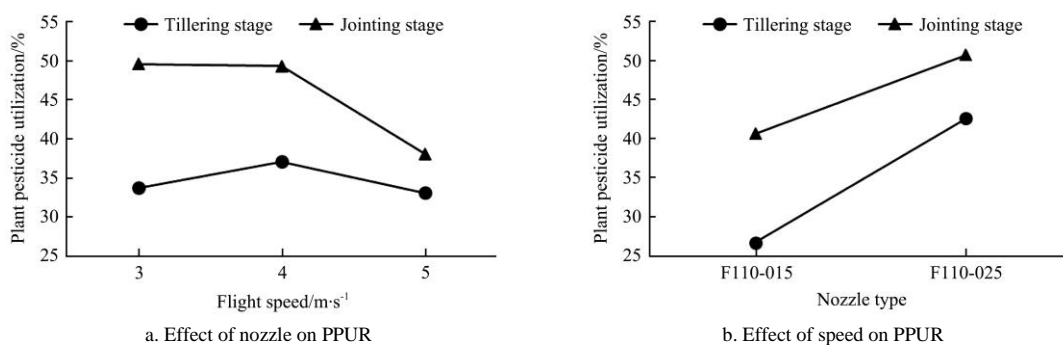


Figure. 4 Influence of various factors on PPUR

**4 Conclusions**

In this study, plant pesticide use efficiency in different growth stages (tillering stage, jointing stage, booting stage) of rice was studied by using polyester card method and rice plant sampling method. The following conclusions were reached:

1) The average of deposition rate of upper polyester card of CE-20 UAV sprayer was 76.1%, 70.0% and 54.2% for tillering stage, jointing stage and booting stage respectively, that mainly affected by wind speed, and loss rates of pesticides was 39.5%,

26.6% and 17.0% respectively, loss rate decreased with the increase of LAI.

2) The results of paired t-test showed that there is no significant difference between polyester card method and plant sampling method for testing the plant pesticide use efficiency, which indicates that the plant pesticide use efficiency test method with plant weight unit area is reliable.

3) Under a height of 2 m and a spray width of 4 m, CE-20 UAV sprayer has optimal operating parameters with 4m/s flight speed and F110-025 nozzle, and plant pesticide use efficiency

was 47.1%, 56.1% and 52.6% for tillering stage, jointing stage and booting stage respectively. The plant pesticide use efficiency of 3W-30 engine-driven knapsack sprayer was 41.8%, 38.6% and 37.9% respectively for each growth stage. CE-20 UAV sprayer has a better plant pesticide use efficiency than 3W-30 engine-driven knapsack sprayer.

### Acknowledgements

We acknowledge that this study was financially supported by National Key Research and Development Program of China (2016YFD0200702), Special project for basic scientific research business expenses of Chinese Academy of Agricultural Sciences (S201807).

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