

Exploring the operation mode of spraying cotton defoliation agent by plant protection UAV

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Abstract: The method for UAV spraying of cotton defoliating agent in the Yellow River basin was investigated in this study through comparison of a one-time pesticide application experiment and a two-time pesticide application experiment. The experiment was carried out using a Jifei P30 multi-rotor electric UAV. The experiment was divided into five different treatments, the first treatment was the one-time pesticide application to Jinfeng 103 cotton, the second treatment was the two-time pesticide application to Jinfeng 103 cotton, the third treatment was the one-time pesticide application to Lumianyan 37 cotton, the fourth treatment was the two-time pesticide application to Lumianyan 37 cotton, and the fifth treatment was blank test. The cotton plant defoliation and opening of bolls were observed at 5, 10, 15, and 20 days under five different treatments, and statistical analysis was conducted to analyze variations in wadding and defoliation rate for the different treatments. The results showed that the effects of defoliation rates and vomiting rates were better than those of the control group, and the effect of the two-time pesticide application of the same variety of cotton was better than that of the one-time pesticide application. By observing defoliation and wadding after applications, the defoliation effect was determined to be faster than the wadding effect. The costs of one-time pesticide application and two-time pesticide application were also compared, and the cost of the two-time pesticide application was approximately 1.58 times as much as the cost of the one-time pesticide application. Therefore, it is suggested to select the two-time pesticide application mode when spraying defoliant agent on cotton.

Keywords: cotton, defoliation, defoliant agent, wadding, UAV, plant protection

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1 Introduction

Cotton is one of the most important crops in the world, with a characteristically large output and low production cost. It is used to make into a variety of fabrics, as well as to produce skin care products, and as a nectar source plant. Cotton is not only the largest economic crop among China's agricultural production, but also a significant commodity related to the national economy and individual livelihood. It is an important resource involving the two major industries of agriculture and textile, the principal source of income for more than 100 million cotton farmers in China, and the primary raw material for the textile industry. Cotton is also a major export commodity for foreign exchange^[1-2].

Cotton experiences late growth, in which the leaves began to dry off and the cotton bolls gradually mature into batting. To prevent cotton wool pollution, improve the quality of the cotton, and provide convenience for mechanical harvest, cotton on the leaf must be picked by a machine before the spraying of ripening agent. Chemical defoliation ripening agent is used intervene in the physiological and biochemical processes of the crop, and can speed

up the growth process of crops, causing them to defoliate in advance. This intervention can accelerate the crop maturity, encouraging defoliation, dehydration, ripening, boll opening, and the secondary growth of leaves^[3,4]. China has conducted research into defoliation ripening agent for cotton over the past 70 years, progressing from initial magnesium chlorate treatments, to the current shedding treasure, and mianhai. Zhu Jijie et al. studied the defoliant sensitivity of 12 different cotton varieties^[5], while Gao Lili and Zou Xi et al. studied the application effect of different agents^[6,7]. Ma Yan et al. sprayed defoliant in Xinjiang cotton fields with an unmanned aerial vehicle (UAV), and studied defoliant, wadding effect, and cotton quality^[8]. Wang Yi et al. studied the effect of defoliation rate and yield of cotton after spraying defoliant^[9].

At present, the cotton producing areas in China are mainly located in Xinjiang and the Yellow River basin. Numerous related defoliant experiments have been conducted, however, due to restrictions arising from climatic conditions and planting environment^[10-12], the mechanization degree in the Yellow River basin is relatively backward compared with Xinjiang^[13,14].

Due to the continuous improvement of agricultural mechanization and the increase in labor costs, mechanized harvesting has become the predominant method of cotton picking^[15]. In this climate, cotton defoliation technology is becoming increasingly essential. In recent years, China's agricultural aviation industry has developed rapidly^[16], and the field of plant protection UAV, one of the important components of the agricultural aviation industry, has attracted extensive attention^[17,18]. As an emerging plant protection operation, UAV aerial application technology has high spraying efficiency, good

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atomization effect^[19-21], low cost, and high efficiency^[22-25]. It is also flexible, being that the operation does not require a special runway, and can access fields that are not easy to enter. The safety of UAV operations arising from the separation of human and machine has also experienced rapid development in the plant protection industry^[26,27].

Cotton in the Yellow River basin is affected in ways unique to the area's varieties, weather, and terrain. In this area, the horizontal branches are longer and cross each other, creating a more dense cover than found in varieties in Xinjiang and other places, which demands higher operation requirements. The mechanized development of cotton in the basin area has dramatically advanced the growing industry in this area^[28-31]. Taking the multi-rotor plant protection UAV as an example, two different application methods of one-time pesticide application and two-time pesticide application are adopted in this paper. Using analysis of efficacy and cost, the results provide a reference for cotton defoliation operations using the same pesticide.

2 Materials and methods

2.1 Instruments and equipment

A P30 four-rotor electric plant protection UAV with a maximum tank capacity of 15 L is used in the experiment. This UAV supports autonomous obstacle avoidance and ground flight, with a working speed of 1-10 m/s, and an operating height of 1-30 m. The spray system consists of a water pump, spray bar, control box, and nozzle. The nozzle adopts a centrifugal nozzle, which drives the liquid into fine droplet particles by centrifugal force. The fog particle diameter is mainly affected by the motor voltage, liquid atomization is uniform, the atomization effect is efficient, and the diameter of the droplets is similar. In order to determine the meteorological environment during the test, it is equipped with a temperature and humidity detector and a grace detector, which are respectively used to detect the temperature, humidity and wind speed during the test to ensure that the meteorological conditions during the test meet the operational requirements.

2.2 Test methods

2.2.1 Test site and test varieties

The test site is located in Wudi County, Binzhou City, in Shandong Province. The total area is more than 2,000 mu, the soil texture of the test plot is saline and alkaline land, and the planting mode of "one film and three rows" is adopted. The equal row spacing of the cotton plants is 76 cm, and the average plant height is 85 cm. The tested cotton varieties are Jifeng 103 and Lumianyan 37. On the day of the first application, the temperature ranged from 22 to 26°C, the relative humidity was 43.4% to 54.5%, and the wind speed was 0.40 to 1.15 m/s. The temperature of the second application was 20 to 25°C, the relative humidity was 47.4% to 62.5%, and the wind speed was 0.31 to 1.23 m/s. These conditions were determined to meet the requirements for the job.

2.2.2 Test agent

50 % active ingredient of thidiazuron and ethephon were used as cotton defoliant, and the additives are special agents for flying defense produced by Anyang Quanfeng Biological Technology Co., Ltd.

2.2.3 Sample point arrangement

The five-point sampling method was adopted in the operating area, and was recorded as region A, B, C, D and E, four cotton

plants with similar growth were selected at each point, tied with red rope and marked on the red rope for later investigation.



Figure 1 UAV test site

2.2.4 Test method

Five treatments were designed, each of which was about one mu in size. The specific dosage of medicament was shown in Table 1.

Table 1 Experimental processing

Deal	Cotton varieties	Spraying agent	
		First day	Seven days later
1	Jifeng103	40 g thidiazuron + 90 mL ethephon +1 mL additives	/
2	Jifeng103	30 g thidiazuron + 60 mL ethephon +1 mL additives	25 g thidiazuron + 50 mL ethephon +1 mL additives
3	Lumianyan37	40 g thidiazuron + 90 mL ethephon +1 mL additives	/
4	Lumianyan37	30 g thidiazuron + 60 mL ethephon +1 mL additives	25 g thidiazuron + 50 mL ethephon +1 mL additives
5	Jifeng103	Water	/

According to the experience of the flying company and the cotton center of Shandong Province, the flying height of the UAV is 2 m, the speed is 2 m/s, the spray volume is 600 ml^[32,33]. When the agent is sprayed only once, 40 g thidiazuron and 90 mL ethephon are used. When the agent is sprayed twice, 30 g thidiazuron and 60 mL ethephon are used for the first time, and after seven days, 25 g thidiazuron and 50 mL ethephon are used, and 1 mL additive is added per mu.

2.3 Survey method

2.3.1 Investigation on the effect of ripening and defoliation of cotton

In this section, the number of leaves and boll (bating and non-bating) of the whole cotton plant that was numbered before application is investigated. The number of leaves and boll (bating and non-bating) remaining after application is reviewed at 5 days, 10 days, 15 days, and 20 days, respectively. The formula for calculating defoliation rate and wadding rate is as follows:

$$D = \frac{T_a - T_b}{T_a} \times 100\%$$

where, D – rate of defoliation, %; T_a – Total number of cotton leaves before application, slice; T_b – Number of cotton leaves remaining at the time of investigation, slice.

$$W = \frac{N_a}{N_b} \times 100\%$$

where, W – Rate of wadding, %; N_a – Cotton boll number, individual; T_a – total number of cotton boll application, individual.

2.3.2 Data analysis

Following data collection at 5, 10, 15 and 20 days after application, SPSS16.0 software is used for statistical analysis of defoliation rate and wadding rate, and the Duncan method is used to analyze significant differences between the two treatments.

3 Results and analysis

At present, there are two main ways of spraying cotton defoliant agent: one-time pesticide application and two-time pesticide application. One-time pesticide application refers to spraying defoliant only once, and two-time pesticide application is to apply again after seven days of the first application. As an emerging operation mode of current agricultural operations, plant protection UAV have been widely promoted due to their high

Table 2 The number of remaining leaves in different regions under different treatment days

Group	Before application					After 5 days of application					After 10 days of application					After 15 days of application					After 20 days of application				
	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
1	246	257	260	266	264	191	182	185	206	199	100	95	102	105	106	47	50	41	53	51	20	20	26	25	23
2	299	300	290	281	311	220	223	216	216	241	110	111	123	119	131	41	43	45	44	47	13	14	16	14	17
3	261	259	266	275	236	193	186	197	205	170	100	96	109	110	99	45	49	51	50	45	19	20	25	25	20
4	280	295	290	279	273	209	220	223	206	209	107	115	103	109	105	40	47	42	43	32	9	4	10	11	11
5	229	236	271	225	226	190	197	205	187	186	160	163	171	150	144	149	151	156	131	131	121	129	131	115	105

Table 3 Analysis of significant differences in defoliation rates between different treatments

Group	5 days later	10 days later	15 days later	20 days later
1	25.51a	60.71a	81.29b	91.80b
2	24.65a	59.87a	85.13ab	95.00a
3	26.72a	60.34a	81.48b	91.61b
4	25.39a	61.95a	85.63a	96.12a
5	13.99b	29.64b	36.58c	46.91c

It can be seen from Table 2: the final effect of the two-time pesticide application of Lumianyan 37 or Jinfeng 103 should be slightly higher than the rate of defoliation for one-time pesticide application, and both are significantly higher than the effect of the water treated control group. In addition, the defoliation effect of the two-time pesticide application in the first 5 days is not as good as that of the one-time pesticide application, but after the second spraying of defoliating agent, the defoliation rate of the two-time pesticide application begins to slowly exceed the one-time pesticide application, and the final defoliation rate of the two-time pesticide application is higher than that of the one-time pesticide application.

Table 3 shows the difference in the defoliation rate after 5 days, 10 days, 15 days, and 20 days after application in different treatments by Duncan method. It can be concluded from the table: There was no significant difference between the first four treatments after 5 days of application and 10 days after application, and the difference was significant after 15 days and 20 days, the defoliation rate of two-time pesticide application was higher than that of one-time pesticide application, and there was always a significant difference between the treatment group and the control group, the defoliation rate of the treatment group was significantly higher than that of the control group.

Figure 2 and Figure 3 shows the defoliation rate of one-time pesticide application and two-time pesticide application. As can be seen from the figure, after 5 days of application, the effect of one-time pesticide application is better than two-time pesticide application, after 10 days of application, the effect of the first

efficiency and good performance. In the experiment, the plant protection UAV of Jifei P30 was used to carry out one-time pesticide application and two-time pesticide application of two varieties of cotton respectively. The flying height of the UAV was 2 m, the speed was 2 m/s, and the particle size of the fog droplet was 130 microns.

3.1 Defoliation rate of different treatments

In this paper, the number of remaining bolls in five experimental groups after spraying defoliant for 5 days, 10 days, 15 days and 20 days were counted, and the defoliation rate was calculated respectively. Meanwhile, the significance of different treatments was analyzed by Duncan method. Table 2 and Table 3 respectively show the number of remaining leaves in different regions under different treatment days and analysis of significant differences in defoliation rates between different treatment.

application is equal to that of the second application, however, 15 days later, the effect of two-time pesticide application is better than that of one-time pesticide application, and there is significant difference. The reason may be that the first application dosage of two-time pesticide application is less than that of one-time pesticide application, after the second application, the effect of two-time pesticide application is better than that of one-time pesticide application. At the same time, combining with the change of leaves, it can be concluded that the time period between 5 days after application and 15 days after application is the time period when the defoliation effect is the most significant.

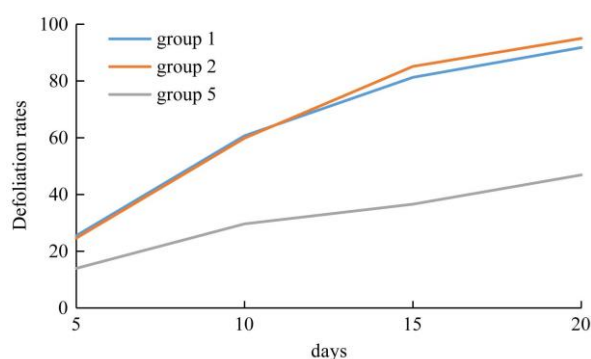


Figure 2 Defoliation rate of groups 1, 2 and 5

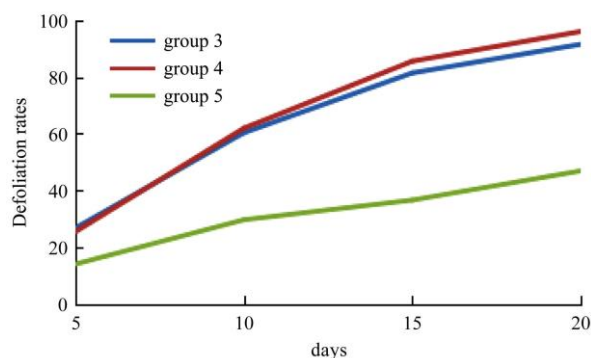


Figure 3 Defoliation rate of groups 3, 4 and 5

3.2 Wadding rate of different treatments

The experiment also counted the number of cotton boll openings in five experimental groups after spraying defoliant for 5 days, 10 days, 15 days and 20 days, the significant differences in vomiting rates between different treatments was analyzed by

Table 4 The number of cotton boll batting number to different days of each treatment

Group	Total number of bells before application					Number of vomits after 5 days of application					Number of vomits after 10 days of application					Number of vomits after 15 days of application					Number of vomits after 20 days of application				
	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
1	56	70	54	59	63	38	39	30	31	39	43	51	40	46	51	49	56	46	50	56	51	61	49	53	59
2	75	73	86	80	86	40	39	47	45	52	51	50	61	56	65	62	65	72	67	73	72	72	80	75	82
3	83	89	83	78	82	55	46	49	41	56	62	70	59	57	65	69	77	67	61	73	73	79	72	69	80
4	79	86	82	77	77	40	52	47	47	39	55	61	59	53	52	68	73	71	64	64	76	81	79	72	75
5	69	82	76	79	83	37	39	41	44	43	45	45	46	52	49	52	54	50	56	53	56	58	52	59	54

Table 5 Significant differences in vomiting rates between different treatments

Group	5 days later	10 days later	15 days later	20 days later
1	58.02a	75.75a	84.37a	89.90b
2	55.62a	70.60b	84.81a	95.35a
3	59.57a	75.36a	83.52a	89.90b
4	56.02a	69.77b	84.76a	95.53a
5	52.53a	61.10c	68.35b	72.01c

As we can see from Table 4: both the final effect of the two-time pesticide application and one-time pesticide application are higher than the effect of the water treated control group, but the change of cotton boll batting number of the two-time pesticide application was not as fast as the one-time pesticide application. In the case of the one-time pesticide application, most of the cotton bolls began to boll after 5 days, but most bolls of the two-time pesticide application began to boll between 10 days and 15 days.

The Duncan method is employed in Table 5 to analyze the significant variances in the wadding rate between different treatments. After 5 days of application, there is no significant difference in the wadding rate between the five treatments, however, the defoliant displayed a significant difference between the control group and the treatment group after 5 days of application, the reason for the analysis may be that the efficacy of ethephon is slower than that of thiazole. After 10 days of application, there is a significant difference between the treatment of two-time pesticide application and the treatment of one-time pesticide application, the effect of one-time pesticide application is better than two-time pesticide application at this time, there was no significant difference after 15 days of application, there was a significant difference between the treatment of the two-time pesticide application after 20 days of application and the treatment of one-time pesticide application. The reason may be that the second effect of two-time pesticide application begins to produce efficacy after 15 days.

Figure 4 and figure 5 shows the vomiting rate of one-time pesticide application and two-time pesticide application. As can be seen from the change of broken line, it is different from defoliation rate, after 5 and 10 days of application, the effect of one-time pesticide application is better than two-time pesticide application, after 20 days of application, the effect of two-time pesticide application is better than that of one-time pesticide application, and there is significant difference. The reason may be the same as defoliant. After the second application of the two-time pesticide application, the effect of the two-time pesticide

Duncan method. Table 4 and Table 5 respectively show the number of cotton boll batting number to different days of each treatment and significant differences in vomiting rates between different treatments.

application began to be more than the one-time pesticide application, but the effect is slower than defoliant, so the effect is obvious in 15-20 days.

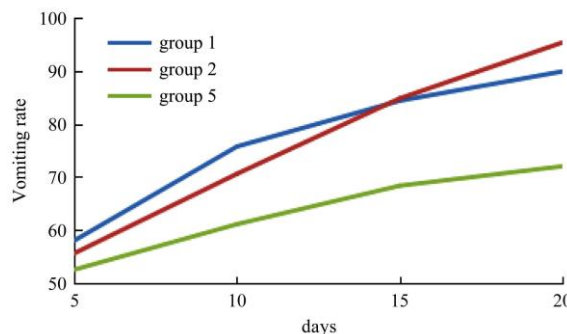


Figure 4 Vomiting rates of group 1 group 2 group 5

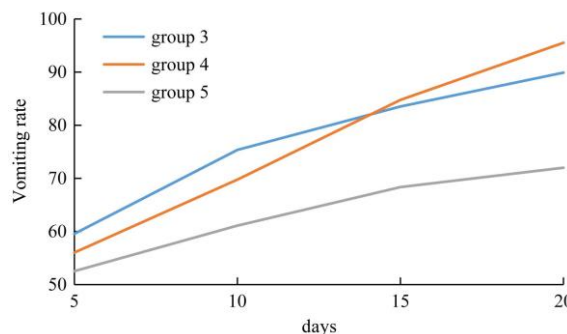


Figure 5 Vomiting rate of group 3 group 4 group 5

3.3 Calculation of the cost of one-time pesticide application and two-time pesticide application

For the convenience of reference, the cost per mu of land under the two operation modes of this experiment are determined, and are provided in Table 6 below.

Table 6 Cost per mu for the two operation modes

Cost	One-time pesticide application	Two-time pesticide application
Thidiazuron	14.8	20.35
Ethephon	3.6	4.4
Additives	0.35	0.7
Labor fee	10	20
Electricity fee	0.096	0.192

Note: the calculation is based on the actual consumption of one mu of land, unit: yuan.

The total cost can be calculated according to the following formula:

$$C = C_t + C_n + C_a + C_l + C_e$$

where, C – Total cost, yuan/667 m²; C_t – Thidiazuron cost, yuan/667 m²; C_n – Ethephon cost, yuan/667 m²; C_a – Additives cost, yuan/667 m²; C_l – Labor cost, yuan/667 m²; C_e – Electricity cost, yuan/667 m².

From the above formula, we can get the cost of a one-time pesticide application per mu is about 28.846 yuan, the two-time pesticide application cost is higher because the two-time pesticide application requires more drugs and two times of labor, the cost of the two-time pesticide application per mu is about 45.642 yuan, and the cost of the second spraying is about 58 % more than that of the first spraying. Considering the economic value of cotton and the complexity of cotton removal, it is suggested the two-time pesticide application mode should be used when spraying defoliant agent to increase defoliation rates and vomiting rates, and reduce the impurity rate in mechanized cotton picking.

4 Discussion

A Jifei P30 multi-rotor electric UAV was used to spray cotton in the Yellow River Basin. The cotton defoliant agent was sprayed with different methods of plant protection to observe the defoliation and wadding effect of cotton, and the cost was calculated to provide a reference for the method of spraying defoliant on cotton using UAV.

From the perspective of defoliation rate and wadding rate, the two-time pesticide application effect is superior to the effect of one-time pesticide application. After 5 or 10 days of application, the defoliation rate and the wadding rate of the two-time pesticide application are lower than one-time pesticide application, the rate of defoliation and the rate of boll opening may be influenced by the amount of medicament used in the first operation of the two-time pesticide application, which is lower than the amount of the agent used in the one-time pesticide application. In addition, according to the defoliation rate and the value of the wadding rate, it can be seen that the influence is not obvious in the first 5 days after the operation, and the effect is more significant in the period from 5 days to 15 days. The effect of two-time pesticide application at 10 days is not as good as that of one-time pesticide application, but the effect of application is more than the one-time at 15 days, it indicates that the effect of the second application begins to take effect. When collecting data, it is observed that the effect of defoliating and flocculation of cotton is not obvious in the first 5 days after application, indicating that the defoliant has obvious effects in the period 5 days to 15 days after application.

The collected data were analyzed by SPSS software. The Duncan method was used to analyze whether there were significant differences between different treatments. The results showed that the defoliation rate of one-time pesticide application and two-time pesticide application had no significant difference in the first 10 days, there was significant difference after 15 days of application, after 20 days, there was significant difference between two-time pesticide application and one-time pesticide application, the defoliation rate of two-time pesticide application was significantly higher than the defoliation rate of one-time pesticide application. For the vomiting rate, there was no significant difference between 5 days after application and 15 days after application, and there was a significant difference between 10 days after application and 20 days after application, and the data showed that the vomiting rate of two-time pesticide application was higher than that of one-time pesticide application.

Comparing the difference between the defoliation rate and the

wadding rate, the defoliation rate is significantly different from the application group and the control group after 5 days of application, but there is no significant variation in the rate of defoliation and the rate of boll opening after 5 days of application, the reason for this may be that the effect of defoliation is faster than that of boll opening.

At the same time, the cost is calculated. It costs approximately 28.846 yuan per mu for one application, and 45.642 yuan per mu for the two-time pesticide application. It is also recommended to select the operation method according to the local cotton condition. It is suggested to select the two-time pesticide application mode when spraying defoliant agent on cotton, especially when the spraying cotton plant is high and the quality is high, avoid the phenomenon of water leakage at the bottom of the leaves, and prevent the leaves from falling off and make the impurity rate too high during cotton picking.

5 Conclusions

A multi-rotor plant protection UAV was taken as an example to spray defoliant on cotton using two different operation methods. The following conclusions can be obtained by analyzing the defoliation and wadding effect of the cotton:

1) When using multi-rotor plant protection UAV to spray defoliants on cotton in the Yellow River Basin, there is a significant difference between the effect of two-time pesticide application and the effect of one-time pesticide application, and the effect of two-time pesticide application is better than the effect of the one-time pesticide application;

2) After spraying defoliant on cotton, the rate of change for defoliation rate and wadding rate was a slow to fast and slow process, and the effect of defoliation was most significant between 5 to 15 days;

3) After spraying the defoliating agent, the defoliation effect was faster than the wadding effect. After spraying the defoliating agent, the defoliation effect was faster than the wadding effect, considering many factors, it is suggested to select the two-time pesticide application mode when spraying defoliant agent on cotton.

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