

# Evaluation of herbicides aerially applied from a small unmanned aerial vehicle over wheat field

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**Abstract:** Wheat is one of the most important crops in the world. Unfortunately, approximately 10% of wheat production was decreased caused by weeds every year. Small Unmanned Aerial Vehicles (UAVs) have been widely applied in plant protection. However, there is few research on weed control via (UAV) over wheat field. In this study, the effects of different spray methods with various herbicides sprayed at different dosages were evaluated in a wheat field. In the meantime, the method of similarity-difference analysis was used to evaluate the influence of multiple factors on the effectiveness of each herbicide, and the grey correlation method was adopted to analyze the indicators of control effectiveness, yield, cost, income and safety. The results showed that: 1) For weed control UAV spray application was better than manually conducted one; 2) B2 (Fluroxypyr-meptyl 20% EC) sprayed from a small UAV exhibited significant suppressive effects on weed growth; 3) C1 (600 mL/hm<sup>2</sup> Fluroxypyr-meptyl 20% EC) was the optimum dosage; 4) The treatment group A1B2C1 (spraying 600 mL/hm<sup>2</sup> Fluroxypyr-meptyl 20% EC via a small UAV) was the best combination in weed control. Additionally, the influence of UAV spraying and manual spraying on the weight of weeds was not obvious, but different herbicides and doses have different promoting effects on weeds height. Nevertheless, herbicides sprayed from UAV increased wheat yield from 8097.58 kg/hm<sup>2</sup> of manual operations to 9283.40 kg/hm<sup>2</sup>. The study may provide novel insights into the application of herbicides sprayed from UAV for weed control in wheat field.

**Keywords:** small UAV, herbicide, wheat, weed control, herbicide dosages, grey correlation method

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## 1 Introduction

Wheat is one of the most important food crops that provides dietary carbohydrates for more than one-third of the world's total population. Wheat production is critical to global food security<sup>[1]</sup>. Being a country with the most population, China is the biggest wheat-producing country. Therefore, ensuring wheat safety remains an urgent task to be developed<sup>[2]</sup>. As we know by now, approximately 10% of wheat production was decreased caused by weeds every year<sup>[3,4]</sup>. Hence, preventing and controlling of weeds in wheat field are important steps to ensure crop production in

modern agriculture system of China<sup>[5]</sup>. Chemical control by manually or mechanically spraying herbicides play important roles in managing weeds. At present, artificial herbicides spraying is still a common method of weeds management in China. This conventional spraying method not only caused high labor intensity and low efficiency, but also increased the probability of poisoning incidents and environmental pollution.

Recently, use of UAV for pesticide application has become an increasing research spotlight. It is more suitable for small farming plots<sup>[6]</sup>. The use of UAV has been already commonly used in East Asian countries such as Japan and Korea. UAV spraying is

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considered as a high efficiency alternative to the conventional manual spray operations and a low-cost choice as compared to the classical manned aerial application. UAVs have various advantages in high efficiency, low poisoning risk, low cost and less effort<sup>[7-10]</sup>. However, the technology adoption rate of small scale farm remains at the development stage in China.

Many studies have been conducted on pesticide spraying of UAV, which focus on the optimization of operation parameters and developing novel applied technologies<sup>[11-19]</sup>. Zheng optimized parameter settings and concluded spraying methods for corns at different growth stages<sup>[11]</sup>. Qin studied the influence of height and velocity of UAV operation on droplet deposition and provided an optimized spraying pattern in the rice fields<sup>[12]</sup>. The influence of the operational parameters of the UAV on the droplet distribution associated with corn borer spraying was investigated and results determined the best liquid concentration of chlorpyrifos and the optimal flight height<sup>[13]</sup>. The effects of tree shape on droplet deposition in citrus trees were also investigated, which demonstrated the front, middle, rear, left and central parts displayed uniform distributions, but the right part of the inverted triangle-shaped trees did not<sup>[14]</sup>. Huang built a Fully Convolutional Network (FCN) method that could generate an accurate weed cover map based on high spatial resolution imagery captured by UAV, which promoted the site-specific weed management<sup>[15]</sup>. Pelosi and Castaldi studied UAV spraying in the early post-emergence stage of maize and achieved a decrease of approximately 37% in the use of herbicides<sup>[16]</sup>. Faical proposed a methodology based on particle swarm optimization to reduce the drift of pesticides by fine tuning the control rules during the spraying of pesticides in crop field<sup>[20]</sup>. With the development of high technologies, such as global positioning systems (GPS), geographic information systems (GIS), remote sensing (RS), variable-rate (VR) and UAV had been increasingly applied in the yield monitor of coffee and wheat, rangeland, agricultural management, especially for fields in mountainous regions and in orchards that the ground machinery can not enter<sup>[11,21]</sup>. These results promote the UAV applications in agriculture, which will be improve the atmosphere of crop protection in the future.

Currently, there are a great many studies on rice<sup>[11]</sup>, corn<sup>[22]</sup> and cotton protection using UAV spraying technology, but very few on wheat. In the present study, UAV spraying herbicides in wheat fields, two different spraying methods (small UAV and artificial operations) with three different herbicides (Florasulam-Haloxifen-methyl 20% WDG, Fluroxypyr-meptyl 20% EC and 2,4-D 1-butyl ester 57% EC) were performed in wheat field. Through the comparison of weed control effect, wheat yield, cost, income and safety, result showed that small UAV was superior to artificial operations, the suitable herbicide and dosage optimization scheme for the operation of small UAV were successfully screened out, which provided a scientific basis for the large-scale application of small UAV.

## 2 Materials and methods

### 2.1 Herbicides

Florasulam-Haloxifen-methyl 20% WDG (10% florasulam + 10% Haloxifen-methyl) (Dow Agrosiences China Co., Ltd.), Fluroxypyr-meptyl 20% EC (Anhui Lantian Agricultural Industry Development Co., Ltd. China) and 2,4-D 1-butyl ester 57% EC (Shandong Shengbang Green Chemical Co., Ltd. China).

### 2.2 Spraying devices and platform

The type of aviation platform was 3WQ-120-type UAV with a

spraying nozzle (LU120-02) (Anyang Quanfeng Biological Technology Co., Ltd. China). Using GPS, the accuracy of the flying height and flying velocity was controlled within 0.5 m and 0.3 m/s, respectively. The artificial sprayer was 3WBS-D-16A type backpack electric sprayer (Zhengzhou Rookie Agricultural Machinery Co., Ltd. China). The main parameters of 3WQ-120-type UAV and 3WBS-D-16A sprayer were presented in Table 1.

**Table 1 Characteristic parameters of the 3WQ120-12 UAV and the 3WBS-D-16A type backpack electric sprayer**

	3WQ120-12	3WBS-D-16A
Rotor	Single rotor ( $\phi$ 2.41 m)	
Type of nozzle	LU120-02	Fan-type
Pressure/MPa		0.15-0.4
Single width/m	5-6	1-2
Spray speed/m·s <sup>-1</sup>	0-6	
Nozzle numbers	2	1
Working height/m	2-6	0.5
Driving speed/m·s <sup>-1</sup>	0-20	0-1
Tank capacity/L	12	16

### 2.3 Experimental design

The experiment was conducted in wheat fields in Anyang Institute of Technology (located in Pangwan Village, Yonghe Township, Anyang County, Anyang City, Henan Province, China, 35°12'N, 114°50'E). The wheat variety was AG0952. Experimental fields were flat terrain, medium fertility, moist soil, and the previous crop planted was corn. The fields were managed during the whole growth period by local farmers.

The field experiments were conducted in three factors completely randomized block design with 5 replicates for each treatment, which were planted in the 60 m × 4.5 m plot area. Factor A was the spraying methods, which was divided into two treatments, A1 (spraying by small UAV) and A2 (spraying by artificial sprayer); Factor B was different of herbicides, which was divided into three treatments, B1 (Florasulam · Haloxifen-methyl 20% WDG), B2 (Fluroxypyr-meptyl 20% EC) and B3 (2,4-D 1-butyl ester 57% EC); Factor C was herbicide dosages, which was divided into four levels, included C1 (either 60 g/hm<sup>2</sup> Florasulam-Haloxifen-methyl 20% WDG or 600 mL/hm<sup>2</sup> Fluroxypyr-meptyl 20% EC or 2,4-D 1-butyl ester 57% EC), C2 (either 90 g/hm<sup>2</sup> Florasulam-Haloxifen-methyl 20% WDG or 900 mL/hm<sup>2</sup> Fluroxypyr-meptyl 20% EC/2,4-D 1-butyl ester 57% EC), C3 (either 120 g/hm<sup>2</sup> Florasulam-Haloxifen-methyl 20% WDG or 1200 mL/hm<sup>2</sup> Fluroxypyr-meptyl 20% EC/2,4-D 1-butyl ester 57% EC), and control (either 0 g/hm<sup>2</sup> Florasulam-Haloxifen-methyl 20% WDG or 0 mL/hm<sup>2</sup> Fluroxypyr-meptyl 20% EC/2,4-D 1-butyl ester 57% EC). The materials were planted on October 12, 2016. 3WQ120-12 plant protection UAV and 3WBS-D-16A type backpack electric sprayer were used for quantitative spray on March 8, 2017.

### 2.4 Evaluation of different treatments on weed control

The population count of the *Descurainia Sophia* (*Sisymbrium sophia* L.) and shepherd's-purse [*Capsella bursa-pastoris* (L.) Medik] were recorded at 0 d, 30 d and 60 d after treatments in 1 m<sup>2</sup> areas of each replicate plot. The control effect was represented as weed dead rate and calculated according to the following formula: Control effect (%) = [(C - T)/C] × 100%. Where *T* is the weed number after spray and *C* is the weed number before spray.

Meanwhile, the herbicides security was evaluated by investigating the color of wheat leaves. The earbearing number,

grains per spike, and plant height were investigated in 1 m<sup>2</sup> areas of two lines per replicate during the wheat mature period. Wheat was harvested on 11 June 2017, and 1000-grain weight and yield were calculated from the individuals collected in 1 m<sup>2</sup> for each replicate after the threshing operation and plant laboratory test. Cost (yuan/hm<sup>2</sup>) was calculated as = herbicide cost (yuan/hm<sup>2</sup>) + artificial spray cost (yuan/hm<sup>2</sup>) + machine cost (yuan/hm<sup>2</sup>). Revenue (yuan/hm<sup>2</sup>) was calculated as = market value (yuan/kg) × yield (kg/hm<sup>2</sup>) – cost (yuan/hm<sup>2</sup>) – farmland cost (other costs including those of farming, fertilizer, watering and harvesting). The safety of the different treatment groups was evaluated by the toxicity and dosage of herbicides.

**2.5 Statistical analysis**

The experimental data were statistically analyzed using the DPS7.05 data processing system through variance analysis with Duncan’s new multiple range test (MRT) at the 5% significance level<sup>[23-25]</sup>. Similarity-difference analysis was performed by IDSCSB(Intelligent Decision System for Crop Similarity-difference Breeding)<sup>[26,27]</sup>.

**3 Results and discussion**

**3.1 Effects of different spraying methods on wheat yield**

Improving crop yield is one of the ultimate goals of herbicides spraying. Therefore it is necessary to clarify the wheat yield effects with different spraying methods. For different spraying methods, the average wheat yield from A1 treatment (herbicides sprayed by small UAV) was 9283.40 kg/hm<sup>2</sup>, which was significantly higher ( $P<0.01$ ) than that of A2 treatment (8097.58 kg/hm<sup>2</sup>) (Figure 1). The result concluded that UAV spraying application was conducive to wheat yield improvement. Furthermore, concrete analysis on the component factors of wheat yields was also performed (Table 2) and the results showed that spraying by either UAV or artificial operations had no effect on earbearing number and grains per spike, whereas the 1000-grain weight was significantly increased after UAV treatment.

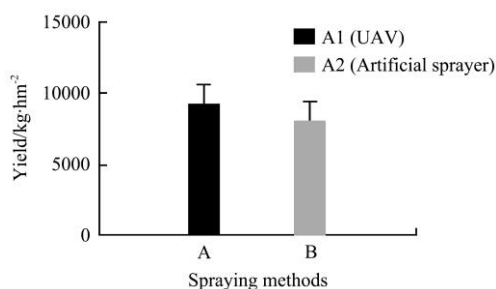


Figure 1 Effects of different spraying methods on wheat yield

**Table 2 Effects of spraying methods and herbicide dosages on component factors of wheat yield**

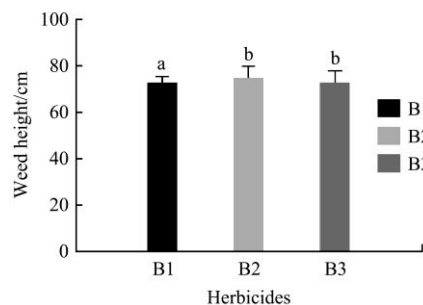
Treatment	No. of spike (mean ± SD)	Kernels per spike (mean ± SD)	1000-grain weight (mean ± SD)
A1	622.42 ± 139.03a	31.16 ± 2.97a	46.15 ± 2.30a
A2	616.55 ± 124.06a	30.88 ± 3.12a	44.46 ± 3.16b

**3.2 Effects of different herbicides on wheat height**

Previous studies showed that spraying wheat herbicides in the field with weed had various degrees of yield-increasing effects (4-20% yield-increasing ranges) under traditional operating conditions, whereas spraying without weed decreased height, photosynthetic characteristics, wheat quality and yield<sup>[28]</sup>. It can be inferred that there was no direct effect of increasing yield with spraying herbicides, but herbicides suppress weed growth or

eliminate weed entirely, indirectly increasing wheat yields by reduction or elimination of competition for water, light and fertilizer.

In order to evaluate the effect of different herbicides on wheat, the wheat height treated with different herbicides was measured. The results showed that the herbicide B2 had a strongest suppressive effect on weed growth ( $P<0.05$ ) in comparison with the herbicide B3 and herbicide B1 (Figure 2). It suggested that B2 was the most effective herbicide in wheat fields.

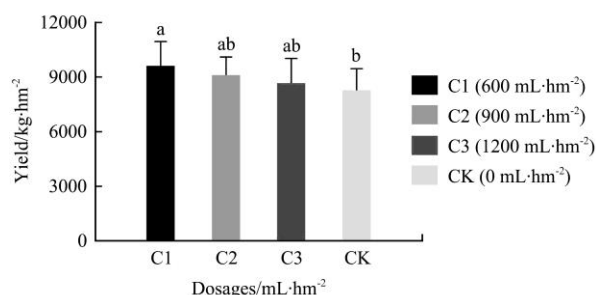


Note: means of five replicates followed by the different letters were statistically different according to Duncan’s new multiple range test ( $P<0.05$ ).

Figure 2 Effects of different herbicides on weed height

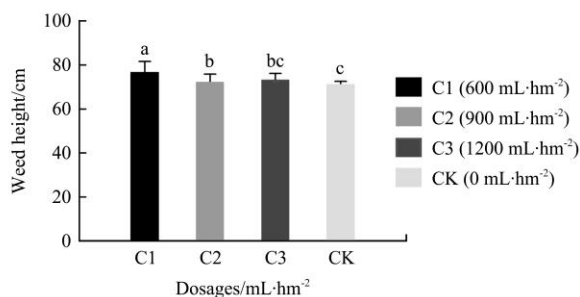
**3.3 Effects of different dosages by small UAV on weed height and wheat yield**

To evaluate the control effects of different dosages on weed, three different dosages of Fluroxypyr-meptyl 20% EC under small UAV spraying method on weed were evaluated. The weeds height and wheat yield were measured. The results of spraying with different dosages showed that height of weed treated by C1 was much lower ( $p<0.01$ ) than that treated by C2, C3 and CK (control) (Figure 3a), implied the C1 was the appropriate dosage treatment. Moreover, wheat yield from the field treated by 600 mL/hm<sup>2</sup> was obviously higher ( $P<0.01$ ) than other treatments, which indicated 600 mL/hm<sup>2</sup> was the appropriate dosage (Figure 3b).



Note: the same letter after the text indicates that the connection trend test of comprehensive traits is not significantly different from each other.

a. Weed height after spraying with different herbicide dosages



Note: means of five replicates followed by the different letters were statistically different according to Duncan’s new multiple range test ( $P<0.05$ ).

b. Weed yield after spraying with different dosages herbicide.

Figure 3 Effects of different dosages by small UAV on weed height and wheat yield

### 3.4 Similarity-difference analysis of comprehensive control of different treatments

To determine the appropriate treatment which resulted in high yield, low cost, environmental protection simultaneously, similarity-difference analysis was conducted on the comprehensive traits of the different treatment groups. By means of the gray correlation method, the weights of revenue, yield, security, control effect and cost were separately determined as 0.2653, 0.2321, 0.1880, 0.1617, and 0.1529 (Table 3). The relatively higher weights of the first three traits indicated their significance for comprehensive evaluation of the different treatment groups. Across all the treatment groups, the overall groups obtained tremendous control effects compared with control. A1B2C1 group had the best yield and revenue, while the control group showed the lowest cost and the highest security. Moreover, based on the results of the similarity-different analysis on the 19 treatment groups, there were two groups with excellent performance (Table 4). The two treatment groups control and A1B2C1, which the comprehensive uniform degrees on the 5 traits were 0.8227 and 0.8215, respectively, indicated that they could reach 82.27% and 82.15% of the ideal extent. However, there was no significant difference between the two treatment groups. The yield and profit of A1B2C1 group reached 11365.57 kg/hm<sup>2</sup> and 20576.1 yuan/hm<sup>2</sup>, the weed control effect reached 98.45% and security (1.5) met the national standards. In a whole, A1B2C1 was the best combination, which can be applied in the wheat production. It was first time adopted the grey correlation method to confirm the weights of five indexes. The result concluded that A1B2C1 groups presented excellent comprehensive performances.

With the development of society and the continuous improvement of living standards, more attention had been paid to the influence of pesticides and its applications on control efficiency, crop yield, and environmental protection. The diversity of results evaluation or multi-factor evaluation put forward new requirements for analysis methods. Some common evaluation methods, such as

**Table 3 Comprehensive performances of different treatment groups**

Treatment combination	Control effect/%	Yield /kg·hm <sup>-2</sup>	Cost /Yuan·hm <sup>-2</sup>	Income /Yuan·hm <sup>-2</sup>	Safety
A1B1C1	100.00	8980.45	270	15135.8	1.0
A1B1C2	99.30	8720.44	330	14488.2	1.1
A1B1C3	99.73	11000.55	390	19581.2	1.2
A1B2C1	98.45	11365.57	220.1	20576.1	1.5
A1B2C2	98.98	8580.43	255	14246.8	1.6
A1B2C3	98.98	10420.52	290	18370.4	1.7
A1B3C1	99.74	9000.45	176	15275	2.0
A1B3C2	99.87	9660.48	188.9	16753.8	2.1
A1B3C3	99.36	8880.45	201.8	14978	2.2
A2B1C1	99.93	7920.40	195	12815.1	1.0
A2B1C2	99.94	8900.45	255	14970	1.1
A2B1C3	99.94	7740.39	315	12288.3	1.2
A2B2C1	98.64	7480.38	145.1	11870.6	1.5
A2B2C2	98.71	7560.38	180	12016.5	1.6
A2B2C3	99.59	8040.40	200	13081.3	1.7
A2B3C1	99.97	9000.45	101	15350	2.0
A2B3C2	100.00	8860.45	113.9	15020.7	2.1
A2B3C3	99.90	6980.35	126.8	10758.8	2.2
Control	84.79	8246.45	75	13671.9	2.5
Weight	0.1617	0.2321	0.1529	0.2653	0.1880

**Table 4 Similarity-difference analysis on comprehensive traits of different treatment groups**

Treatment combination	Integrated identity degree	Contact trend value	Contact trend	Comment	Order
A1B1C1	0.6579	1.9231	Micro-identity trend	Common	14
A1B1C2	0.6429	1.8003	Micro-identity trend	Common	17
A1B1C3	0.7580	3.1322	Weak identity trend	Better	7
A1B2C1	0.8215	4.6022	Strong identity trend	Excellent	2
A1B2C2	0.6842	2.1666	Micro-identity trend	Common	11
A1B2C3	0.7771	3.4863	Weak identity trend	Better	6
A1B3C1	0.7576	3.1254	Weak identity trend	Better	8
A1B3C2	0.7934	3.8403	Weak identity trend	Better	5
A1B3C3	0.7574	3.1220	Weak identity trend	Better	9
A2B1C1	0.6226	1.6497	Micro-identity trend	Common	18
A2B1C2	0.6641	1.9771	Micro-identity trend	Common	13
A2B1C3	0.6047	1.5297	Micro-identity trend	Common	19
A2B2C1	0.6572	1.9172	Micro-identity trend	Common	15
A2B2C2	0.6530	1.8818	Micro-identity trend	Common	16
A2B2C3	0.6791	2.1162	Micro-identity trend	Common	12
A2B3C1	0.8073	4.1894	Weak identity trend	Better	3
A2B3C2	0.7949	3.8757	Weak identity trend	Better	4
A2B3C3	0.6987	2.3190	Weak identity trend	Better	10
Control	0.8227	4.6402	Strong identity trend	Excellent	1

variance analysis or the t-test, involve only one factor or index, and thus it urgently need to seek a comprehensive evaluation method suitable for multiple factors. In present work, the grey correlation method<sup>[29,30]</sup> was adopted to evaluate the weights of five indexes, and similarity-difference analysis on the treatment groups was conducted. This method concluded that A1B2C1 group presented excellent comprehensive performances, which was consistent with the actual results. This indicated that the grey correlation method had a good ability of analysis and evaluation.

## 4 Conclusions

In this study, the herbicides sprayed with UAV on weed control in wheat field was explored. Different herbicides and dosages were conducted to explore the application conditions of small UAV. The main conclusions are as follows: 1) UAV spraying was more effective than artificial spraying. 2) Herbicide B2 had a strongest suppressive effect on weed growth under small UAV condition. 3) C1 showed the best weed control activity than other dosages. 4) The treatment group A1B2C1 by small UAV was the best combination in weed control. In addition, the grey correlation method was first adopted to analyze the weights of five indexes in the application of UAV, which can easily provide us the core factors and show the good evaluation ability. The present work also indicated a significant potential application of the small UAV in future agricultural production.

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The authors declare no conflict of interest.

## [References]

- [1] Zou B H, Ding Y, Liu H, Hua J. Silencing of copine genes confers common wheat enhanced resistance to powdery mildew. *Mol Plant Pathol*, 2018; 19(6): 1343–1352. doi: 10.1111/mpp.12617
- [2] Meng Y H, Lan Y B, Mei G Y, Guo Y W, Song J L, Wang Z G. Effect of aerial spray adjuvant applying on the efficiency of small unmanned aerial vehicle on wheat aphids control. *Int J Agric & Biol Eng*, 2018; 11(5): 46–53. doi: 10.25165/j.ijabe.20181105.4298
- [3] Hume L. Yield losses in wheat due to weed communities dominated by green foxtail [*Setaria viridis* (L.) BEAUV.]: a multispecies approach. *Can J Plant Sci*, 1989; 69(2): 521–529. doi: 10.4141/cjps89-063
- [4] Elliott B R, Lumb J M, Reeves T G, Telford T E. Yield losses in weed-free wheat and barley due to post-emergence herbicides. *Weed Research*, 1975; 15(2): 107–111. doi: 10.1111/j.1365-3180.1975.tb01107.x
- [5] Glass R C, Walters K F, Gaskell P H, Lee Y C, Thompson H M, Emerson D R, Gu X J. Recent advances in computational fluid dynamics relevant to the modelling of pesticide flow on leaf surfaces. *Pest Management Science*, 2010; 66(1): 2–9. doi: 10.1002/ps.1824
- [6] Wang G B, Lan Y B, Qi H X, Chen, P C, Hewitt A, Han Y X. Field evaluation of an unmanned aerial vehicle (UAV) sprayer: effect of spray volume on deposition and the control of pests and disease in wheat. *Pest Management Science*, 2019; 75(6): 1546–1555. doi: 10.1002/ps.5321
- [7] Xue X Y. Effects of N-3 UAV spraying methods on the efficiency of insecticides against planthoppers and *Cnaphalocrocis medinalis*. *Acta Phytophyl Acica Sinca*, 2013; 40(3): 273–278. (in Chinese)
- [8] Zhou Z Y, Zang Y, Luo X W, Lan Y B, Xue X Y. Technology innovation development strategy on agricultural aviation industry for plant protection in China. *Trans of the CSAE*, 2013; 29(24): 1–10. (in Chinese)
- [9] Vetrilla A R, Fasano G, Accardo D. Attitude estimation for cooperating UAVs based on tight integration of GNSS and vision measurements. *Aerosp Sci Technol*, 2019; 84: 966–979. doi: 10.1016/j.ast.2018.11.032
- [10] Kwak G H, Park N W. Impact of Texture Information on Crop Classification with Machine Learning and UAV Images. *Appl Sci*, 2019; 9: 643–660. doi: 10.3390/app9040643
- [11] Zheng Y J, Yang S H, Zhao C J, Chen L P, Lan Y B, Tan Y. Modelling operation parameters of UAV on spray effects at different growth stages of corns. *Int J Agr Biol Eng*, 2017; 10(3): 57–66. doi: 10.3965/j.ijabe.20171003.2578
- [12] Qin W C, Qiu B J, Xue X X, Chen C, Xu F Z. Droplet deposition and control effect of insecticides sprayed with an unmanned aerial vehicle against plant hoppers. *Crop Protection*, 2016; 85: 79–88. doi: 10.1016/j.cropro.2016.03.018
- [13] Gao Y Y, Zhang Y T, Zhang N, Niu L, Zheng W W, Yuan H Z. Primary studies on spray droplets distribution and control effects of aerial spraying using unmanned aerial vehicle (UAV) against Wheat Midge. *Crops*, 2013; (2): 139–142. (in Chinese)
- [14] Tang Y, Hou C J, Luo S M, Lin J T, Yang Z, Huang W F. Effects of operation height and tree shape on droplet deposition in citrus trees using an unmanned aerial vehicle. *Comput Electron in Ag*, 2018; 148: 1–7. doi: 10.1016/j.compag.2018.02.026
- [15] Huang H S, Deng J Z, Lan Y B, Yang A Q, Deng X L, Zhang L. A fully convolutional network for weed mapping of unmanned aerial vehicle (UAV) imagery. *Plos One*, 2018; 13(4): e0196302. doi: 10.1371/journal.pone.0196302
- [16] Castaldi F, Pelosi F, Pascucci S, Casa R. Assessing the potential of images from unmanned aerial vehicles (UAV) to support herbicide patch spraying in maize. *Precis Agric*, 2016; 18(1): 76–94. doi: 10.1007/s11119-016-9468-3
- [17] Huang H S, Deng J Z, Lan Y B, Yang A Q, Zhang L, Wen S, Zhang H H, Zhang Y L, Deng Y S. Detection of *Helminthosporium* Leaf Blotch Disease Based on UAV Imagery. *Appl Sci*, 2019; 9(3): 558. doi: 10.3390/app9030558
- [18] Xue X Y, Lan Y B. Agricultural aviation applications in USA. *Trans of the CSAE*, 2013; 44(5): 194–199. (in Chinese)
- [19] Bravo-Mosquera P D, Cerón-Muñoz H D, Díaz-Vázquez G, Martini C F. Conceptual design and CFD analysis of a new prototype of agricultural aircraft. *Aerosp Sci Technol*, 2018; 80: 156–176. doi: 10.1016/j.ast.2018.07.014
- [20] Façal B S, Pessin G, Geraldo F P, Carvalho A, Furquim G, Ueyama J. Fine-tuning of UAV control rules for spraying pesticides on crop fields. 2014 IEEE 26th International Conference on Tools with Artificial Intelligence, 2014; 527–533. doi: 10.1109/ictai.2014.85
- [21] Huang Y, Hoffmann W C, Lan Y, Wu W, Fritz B K. Development of a Spray System for an Unmanned Aerial Vehicle Platform. *Appl Eng Agric*, 2009; 25(6): 803–809. doi: 10.13031/2013.29229
- [22] Ding X H, Wang N, Wang X W, Fu K Y, Tursun A, He J, Yang J, Fu W J, Guo W C. Studies on the control effect of ultra-low volume aerial spray using unmanned aerial vehicle (UAV) against the corn borer. *Xinjiang Agricultural Sciences*, 2017; 54(3): 479–488. (in Chinese)
- [23] Soeno K, Taira Y, Atsuta M. Influence of formaline cresol on bond strength of adhesive luting agents to dentin. *J Oral Rehabil*, 2000; 27(7): 623–628. doi: 10.1046/j.1365-2842.2000.00543.x
- [24] Harter H L. Critical Values for Duncan's New Multiple Range Test. *Biometrics*, 1960; 16(4): 671–685. doi: 10.2307/2527770
- [25] Sallato B V, Torres R, Zoffoli J P, Latorre B A. Effect of boscalid on postharvest decay of strawberry caused by *Botrytis cinerea* and *Rhizopus stolonifer*. *Span J Agric Res*, 2007; 5(1): 67–78. doi: 10.5424/sjar/2007051-224
- [26] Guo R L, Yang C L, Guan L, Hou J H, Wang K, Song Z J, He M L, Jia H Q. Study on Identical and Different Analysis Method of Wheat Variety Regional Test. *Journal of Triticeae Crops*, 2001; 21(3): 60–63. (in Chinese)
- [27] Guo R L, Wang Z Z. Intelligent decision system for crop similarity-difference breeding and its applications. Peking: Science Press, 2014. pp.152–171.
- [28] Yuan W, L R G, Zhou D B, L J Q, Yang L N, Wei L. Screening Test on Different Herbicide of Wheat. *Modern Agricultural Science & Technology*, 2017; (2): 85, 87. (in Chinese)
- [29] Ebert T A, Taylor R A J, Downer R A, Franklin R H. Deposit structure and efficacy 2-Trichoplusiani and Fipronil. *Pesticide Science*, 1999; 55: 793–798. doi: 10.1002/(SICI)1096-9063(199908)55:8<793::AID-PS14>3.0.CO;2-0
- [30] Wang X L, Zhang Z Y, Fu J, Li G. Effects of seeding rate combined with herbicide application on weeds and wheat growth under the condition of rice straw returning. *Jiangsu Journal of Agricultural Sciences*, 2017; 33(2): 307–313. (in Chinese)