EXPERIMENTAL STUDY OF SINGLE-ROTOR UAV ON DROPLET DEPOSITION DISTRIBUTION IN SOYBEAN FIELD

ZHANG, K. F. – ZHANG, Z. – ZHANG, Y. H. – LI, H.*

*College of Mechanical and Electrical Engineering, Henan Agricultural University, Zhengzhou
450002, China*

**Corresponding author
e-mail: chungbuk@163.com*

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Abstract. It is particularly important to improve soybean yield and its management in the middle and late stage. Therefore, in view of the difficult problems of traditional field management machines, such as difficult operation, seedling pressing and so on. In this paper, the following two aspects of experimental research are carried out: the wind field distribution characteristics of single-rotor Unmanned Aerial Vehicle (UAV); the contrast test of the deposition distribution of different types of UAV. The spray test of single-rotor UAV in the middle and late stage of soybean was carried out to optimize the operation parameters of UAV. The experimental data is provided to improving the application of field management and UAV application technology in the middle and late stages of soybean production. The results show that the droplets of single rotor UAV can reach the lower part of soybean canopy, and the density of droplets can be more than 15/cm². The data also provides technical support for experimental study.

Keywords: *plant protection, unmanned aerial vehicle, Huang-Huai-Hai area, wind field, droplet density*

Introduction

Agriculture is the foundation of China's economic construction and development, and the guarantee of the country's prosperity and strength. For a long time, soybean has been loved by people all over the world because of its high quality edible oil, excellent plant protein and many kinds of active substances which are beneficial to the human body (Yang, 2010; Chen et al., 2017^a; Zhang et al., 2015). Soybean, as a feed crop, food crop, oil crop, cash crop and vegetable crop, has a large cultivation area and yield in the United States, Brazil and other countries. With a long planting history, China is one of the major producers of soybean (Zhang, 2007).

In recent years, the domestic demand for soybean has increased year by year, but the soybean output in our country is far from satisfying the domestic demand, which leads to a situation where we have to rely on a large number of imported foreign soybeans. This situation directly threatens the food security of China (Yang et al., 2008; Chen et al., 2017^b).

Figure 1 shows the statistics of Chinese soybean imports from 2012 to 2017. According to the statistics of the General Administration of Customs from January to December 2017, the total amount of imported soybeans has reached 9.55×10^7 t, an increase of 1.16×10^7 t compared to 8.391×10^7 t in 2016. The data of the National Bureau of Statistics shows that the total output of legumes (soybeans and other miscellaneous beans) in China is about 1.9×10^7 t, which is the direct result of the 6.52×10^5 hm² increase in soybean planting area (Lou et al., 2017).

At present, the largest soybean production area in China includes three provinces in northeast China, followed by the summer soybean production area in Huang-Huai-Hai region, where the annual soybean production accounts for about 30% of the total

soybean production in China. Compared with the large-scale self-propelled spraying machinery and the operation mode of agricultural plant protection aircraft in the three provinces of northeast China, soybean plant protection in Huang-Huai-Hai area is mainly carried out by manual sprayer and backpack motor sprayer. This limits the operation of large-scale plant protection machinery because of the characteristics of land management mode and small plot in Huang-Huai-Hai area. At the same time, the development of pesticide application technology in our country, especially the development of pesticide application machinery, is lagging behind in the worsening of diseases and insect pests (Liu et al., 2015; Chen et al., 2017^c; Qin et al., 2014). There are still many problems in the prevention and control of disease and pests, and the demand for soybean in China has been high all the time, but the soybean output cannot meet the change of this situation, which results in the need to import a large number of foreign soybeans, posing a direct threat to food security in our country. 86% soybean demand depends on imports and the imports in 2017 set a high record again, which is a further increase trend.

Figure 1. Soybean import quantity statistics

The development of UAV for plant protection in recent years has offered a new idea for soybean field plant protection (Jin et al., 2016). Single-rotor UAV has been widely used in agricultural plant protection because of its single wind field, uniform spraying, strong penetration, etc. (Gong and Fu, 2008; Guo et al., 2014; Xu et al., 2017). In order to solve the problems existing in soybean field management at the present stage, single rotor plant protection UAV was used in the field experiment in the middle and late stage of soybean, in order to solve the difficulty of traditional field management machine, which enter the soybean field in the middle and late stage of soybean, whose ridge was sealed. It solves pressing seedlings and other difficult problems, too. The field operation parameters of UAV were optimized, and the experimental data and technical support were provided for the application of field management and UAV application technology in the middle and late stages of soybean production. So wind field tests for a single-rotor UAV were carried out in this paper.

The influence of operation speed, flight height and the addition of flight control auxiliary equipment on droplets deposition was analyzed, and the optimal operation parameters in different periods were obtained. Providing field operation and the

optimization of key operation parameters for the applicability of plant protection unmanned aerial vehicle in soybean, are to solve the problem of landing for traditional spraying way during the middle and late stage.

Wind field tests for single-rotor UAV

Material

The test model is the electric single-rotor UAV (Mercury one), which is powered by a high-performance polymer lithium battery and is equipped with a remote control and a matching spray system, as is shown in *Figure 2*. The spray rod is adjustable which is installed with two fan-shaped spray nozzles with spray width of generally 7 m, different types of sprayers can be changed according to the use of different pesticides. Meanwhile, in order to measure wind speed, wind direction and temperature and humidity, we need to prepare multichannel anemometer, computer, temperature and humidity tester (CEM DT-615), portable anemometer (LB-SD2) and timer.

Figure 2. Anelectric single-rotor UAV (Mercury one)

Test method

The experiment was carried out in an experiment plot of Henan Agricultural University. During the test, the wind direction and wind speed were measured with a multichannel anemometer and a handheld anemometer (LB-SD2) at the test site. A temperature and humidity tester (CEM DT-615) is used to record the temperature of the test site and the time required for the test is recorded by a timer. The schematic diagram of the working principle is shown in *Figure 3*.

The wind field test of single-rotor plant UAV needs to determine the boundary of wind field. The multichannel anemometer and the handheld anemometer were used to find the boundary of the wind field (wind speed less than 0.2 m/s), and the boundary of the wind field was recorded.

Before the wind field test was carried out, it was necessary to determine the measurement point of the test, which started from the vertical bottom of the rotor of the UAV (as shown in the *Fig. 3*). Below the rotor of the plant protection UAV was the “O” point of the center. The wind field was measured all the way to the boundary, which was measured with a tape ruler every 0.5 meters. And eight directions were measured in one torus. In the direction of height Z, the height of soybean at branching stage and pod-setting stage were recorded at 0.5 m, 1 m, 1.5 m and 2 m respectively. The median

volume diameter (D_{50}) of agriculture flat-fan nozzle were used (Zhao et al., 2009). The spraying dose was 450 L/ha. The speed of the UAV was 5 m/s. The experiments had been replicated for three times.

Through the wind field test, the best flying altitude range of the single-rotor UAV was obtained. Within the same scope, the single-rotor plant UAV can achieve better spray drop deposition distribution compared to the multi-rotor UAVs.

Figure 3. Wind farm test layout

Results and discussion

In the wind field test, the temperature is 17.5 °C, the wind speed is 0.2 ~ 1.5 m/s and the wind direction are southwest. During the experiment, the head of the drone was placed westward, and the fixed height of the drone was adjusted to 2.88 m. The measured data of each measurement point in the test are shown in *Table 1*.

As shown in *Figure 4*, the wind speed distribution of 0.5 m, 1 m, 1.5 m and 2 m from the plant canopy below the rotor shows that the distribution of wind field at different altitudes is basically similar. With the decrease of distance from the plant canopy, the wind speed is smaller. The decrease of the velocity below the center of the rotor is the fastest. From the wind field test data of *Table 1* and *Figure 4* and the simulation diagram of actual wind field test, it can be seen that the wind speed increases gradually with the increase of the center distance of the rotor axis in the range of rotor span of the single-rotor UAV. Outside the wingspan of the rotor, the wind speed decreases

gradually. In the rotor height direction, the wind speed increases first and then declines with the rise of the distance from the rotor. The trend is that the maximum wind speed is in the range of 1.5 m below the rotor, and the wind speed reaches about 12 m/s.

Table 1. Wind field test data

X/m	Y/m	Z/m	Wind (m/s)	X/m	Y/m	Z/m	Wind (m/s)	X/m	Y/m	Z/m	Wind (m/s)	X/m	Y/m	Z/m	Wind (m/s)
0.0	-2.5	1.0	0.3	0.0	-2.5	1.5	1.5	0.0	-2.5	2.0	1.9	0.0	-2.5	2.5	2.1
-0.5	-0.5	1.0	5.7	-0.5	-0.5	1.5	7.8	-0.5	-0.5	2.0	9.8	-0.5	-0.5	2.5	11.0
-1.0	-1.0	1.0	7.1	-1.0	-1.0	1.5	10.5	-1.0	-1.0	2.0	9.9	-1.0	-1.0	2.5	9.4
-1.5	-1.5	1.0	7.0	-1.5	-1.5	1.5	4.0	-1.5	-1.5	2.0	2.1	-1.5	-1.5	2.5	2.8
-2.0	-2.0	1.0	3.5	-2.0	-2.0	1.5	1.0	-2.0	-2.0	2.0	0.8	-2.0	-2.0	2.5	0.5
-2.5	-2.5	1.0	1.9	-2.5	-2.5	1.5	0.0	-2.5	-2.5	2.0	0.0	-2.5	-2.5	2.5	0.3
-0.5	0.0	1.0	6.4	-0.5	0.0	1.5	7.1	-0.5	0.0	2.0	9.4	-0.5	0.0	2.5	11.0
-1.0	0.0	1.0	6.8	-1.0	0.0	1.5	8.2	-1.0	0.0	2.0	9.4	-1.0	0.0	2.5	11.3
-1.5	0.0	1.0	7.7	-1.5	0.0	1.5	4.9	-1.5	0.0	2.0	3.1	-1.5	0.0	2.5	1.9
-2.0	0.0	1.0	7.3	-2.0	0.0	1.5	5.2	-2.0	0.0	2.0	4.3	-2.0	0.0	2.5	2.9
2.5	0.0	1.0	2.2	2.5	0.0	1.5	0.5	2.5	0.0	2.0	0.8	2.5	0.0	2.5	1.7
-0.5	0.5	1.0	5.7	-0.5	0.5	1.5	7.8	-0.5	0.5	2.0	9.8	-0.5	0.5	2.5	11.0
-1.0	1.0	1.0	7.1	-1.0	1.0	1.5	10.5	-1.0	1.0	2.0	9.9	-1.0	1.0	2.5	9.4
-1.5	1.5	1.0	7.0	-1.5	1.5	1.5	4.0	-1.5	1.5	2.0	2.1	-1.5	1.5	2.5	2.8
-2.0	2.0	1.0	3.5	-2.0	2.0	1.5	1.0	-2.0	2.0	2.0	0.8	-2.0	2.0	2.5	0.5
-2.5	2.5	1.0	1.9	-2.5	3.5	1.5	0.0	-2.5	2.5	2.0	0.0	-2.5	2.5	2.5	0.3
0.0	0.5	1.0	4.0	0.0	0.5	1.5	4.5	0.0	0.5	2.0	7.1	0.0	0.5	2.5	6.1
0.0	1.0	1.0	7.5	0.0	1.0	1.5	7.1	0.0	1.0	2.0	5.2	0.0	1.0	2.5	5.6
0.0	1.5	1.0	3.3	0.0	1.5	1.5	0.3	0.0	1.5	2.0	0.0	0.0	1.5	2.5	0.8
0.0	2.0	1.0	2.8	0.0	2.0	1.5	1.9	0.0	2.0	2.0	1.5	0.0	2.0	2.5	2.4
0.0	2.5	1.0	2.1	0.0	2.5	1.5	0.3	0.0	2.5	2.0	0.0	0.0	2.5	2.5	0.3
0.5	0.5	1.0	5.7	0.5	0.5	1.5	7.8	0.5	0.5	2.0	9.8	0.5	0.5	2.5	11.0
1.0	1.0	1.0	7.1	1.0	1.0	1.5	10.5	1.0	1.0	2.0	9.9	1.0	1.0	2.5	9.4
1.5	1.5	1.0	7.0	1.5	1.5	1.5	4.0	1.5	1.5	2.0	2.1	1.5	1.5	2.5	2.8
2.0	2.0	1.0	3.5	2.0	2.0	1.5	1.0	2.0	2.0	2.0	0.8	2.0	2.0	2.5	0.5
2.5	2.5	1.0	1.9	2.5	2.5	1.5	0.0	2.5	2.5	2.0	0.0	2.5	2.5	2.5	0.3
0.5	0.0	1.0	6.4	0.5	0.0	1.5	7.1	0.5	0.0	2.0	9.4	0.5	0.0	2.5	11.0
1.0	0.0	1.0	6.8	1.0	0.0	1.5	8.2	1.0	0.0	2.0	9.4	1.0	0.0	2.5	11.3
1.5	0.0	1.0	7.7	1.5	0.0	1.5	4.9	1.5	0.0	2.0	3.1	1.5	0.0	2.5	1.9
2.0	0.0	1.0	7.3	2.0	0.0	1.5	5.2	2.0	0.0	2.0	4.3	2.0	0.0	2.5	2.9
2.5	0.0	1.0	2.2	2.5	0.0	1.5	0.5	2.5	0.0	2.0	0.8	2.5	0.0	2.5	1.7
0.5	-0.5	1.0	5.7	0.5	-0.5	1.5	7.8	0.5	-0.5	2.0	9.8	0.5	-0.5	2.5	11.0
1.0	-1.0	1.0	7.1	1.0	-1.0	1.5	10.5	1.0	-1.0	2.0	9.9	1.0	-1.0	2.5	9.4
1.5	-1.5	1.0	7.0	1.5	-1.5	1.5	4.0	1.5	-1.5	2.0	2.1	1.5	-1.5	2.5	2.8
2.0	-2.0	1.0	3.5	2.0	-2.0	1.5	1.0	2.0	-2.0	2.0	0.8	2.0	-2.0	2.5	0.5
2.5	-2.5	1.0	1.9	2.5	-2.5	1.5	0.0	2.5	-2.5	2.0	0.0	2.5	-2.5	2.5	0.3

It can be seen from *Figure 5* that the wind speed gradually decreases with the decrease of the rotor height within the span of the rotor, and the wind speed is affected by the plant canopy effect about 0.5 m away from the plant canopy, and the wind speed decreases gradually from the center of the rotor to the outside. Outside the wingspan, the wind velocity in the direction of height is not obviously weakened.

Figure 4. Different heights wind farm test plan. (Note: Z is the height from the plant canopy)

Figure 5. Wind farm distribution map in the vertical direction of the rotor

Taking the plant canopy as the reference and the rotor axis of the single-rotor UAV as the center, the vertical wind field were measured vertically up the plant canopy, and the vertical wind field data were obtained. The following conclusions are drawn from the analysis:

1. At the same height from the plant canopy, the wind velocity value is positively correlated with the axis distance within the wingspan range, and the wind

- speed increases gradually with the increase of the distance, and decreases gradually beyond the wingspan range until the boundary of the wind field.
2. In the direction of altitude, the value of wind velocity is positively correlated with the height off the plant canopy.
 3. The maximum wind speed is 1-2.5 m above the plant canopy, and the maximum wind speed is 12.9 m/s. Therefore, in the field operation, the flying altitude of the single-rotor UAV is best within this range, which is favorable for the airflow and droplets to reach the bottom of the canopy.
 4. Under the influence of plant canopy effect, turbulence will appear in the wind field below 1 m, and there is no definite rule.

Spray deposition contrast test

In order to test the difference between single-rotor plant UAV and multi-rotor plant protection drone, different models were selected to carry out. The spray tests of S40 single rotor, M23 electric four rotors and M8A electric eight rotor plant protection UAV were carried out in soybean field, and the spray drop deposition distribution of different types of UAV was compared and analyzed.

Materials and methods

Experimental laboratory materials and equipment

In order to compare the effects of droplet deposition with Mercury 1 electric single-rotor UAV, three different UAV were prepared for soybean field experiments, as shown in *Figure 6*. The parameters of the three UAV are shown in *Table 2*.

Figure 6. Three kinds of UAV

Table 2. Main parameters

Type	S40	M23	M8A
Size (mm × mm × mm)	2165 × 2400 × 720	1318 × 1318 × 685	1360 × 1360 × 650
Maximum (load/L)	20	10	10
Flight speed(m/s)	5	5	5
Flight height(m)	1-3	1-3	1-3
Spraying width(m)	4-7	4-6	4-5
Number of sprinklers	5	4	6

Reagent preparation

The analytical instrument is micro-spectrophotometer with a maximum absorption wavelength of 508 nm. First, prepare labeling group, use 500 ml volumetric flask to prepare 1 g/L liquid containing carmine, extract 50 ul, 150 ul, 250 ul, 350 ul, 450 ul, 550 ul, 650 ul, 750 ul, 850 ul, 950 ul solution with pipette to be placed in 10 ml volumetric flask, balance, measure the absorbance, repeat each test three times to obtain average standard curve. In order to indicate deposition quantity with ratio of carmine, curve model of absorbance versus carmine solution concentration was established. Determination coefficient was calculated by linear regression curve fitting as $R^2 = 0.997$. As measurement of deposition quantity needs test of dilution concentration, relationship between carmine solution concentration and absorbance was obtained via variable conversion:

$$C = 0.0363A - 0.0016 \quad (\text{Eq.1})$$

where C is mass concentration (g/L) of the carmine solution and A is absorbance of the carmine solution.

Test method

The experiment was carried out in Liangshan county demonstration base of “Research on high-yield and high-efficiency mechanization production technology and supporting equipment of soybean”. The experiment was carried out in the middle and late stages of soybean growth. The row spacing and plant height of soybean in the experimental field were 40 cm and 90 cm respectively. The spray liquid used in this experiment is 4 g/L rouge aqueous solution, and the droplet collection card is used to collect the droplet. In the field experiment of soybean, three groups of spray tests were compared in the range of spraying in the same plant protection unmanned aerial vehicle (UAV) operation, and 8 points were continuously arranged at 1.2 m interval in the transverse direction, and 8 points were arranged continuously in the same plant protection unmanned aerial vehicle (UAV) operation. Longitudinally: corresponding transverse, control test every 5 meters, continuous arrangement of 3 each collecting point, the upper, middle and lower layers are arranged to collect droplets acquisition card (Fig. 7). Every time the plant protection drone flies along the set axis, in order to stabilize the test operation, the aircraft hovers and takes off at 10 m in the acquisition point, and stops operation after 10 min away from the acquisition point. The temperature and humidity meter and wind speed and wind direction meter were used to measure and record the environmental parameters during the plant protection unmanned aerial vehicle operation.

Figure 7. Collection point layout

Results and discussion

Test results of droplet deposition distribution

The data of droplet deposition and density of droplet deposition are shown in Table 3.

Table 3. Mean value of droplet deposition

Number	S40 Electric single rotor		M23 Electric four rotor		M8A Electric eight rotor	
	Deposits (cm ²)	Deposition (μL/cm ²)	Deposits (cm ²)	Deposition (μL/cm ²)	Deposits (cm ²)	Deposition (μL/cm ²)
A0-1	39.2	0.210	23.0	0.047	18.5	0.036
A0-2	62.0	0.122	21.4	0.018	18.0	0.016
A0-3	11.8	0.027	5.2	0.003	5.8	0.004
A1-1	27.1	0.125	15.7	0.012	41.1	0.067
A1-2	29.7	0.526	21.8	0.022	45.9	0.072
A1-3	20.4	0.049	11.9	0.010	15.4	0.026
A2-1	44.5	0.330	41.1	0.115	61.7	0.977
A2-2	45.3	0.149	43.4	0.097	58.6	0.264
A2-3	9.5	0.030	13.8	0.012	21.6	0.047
A3-1	35.1	0.302	21.3	0.035	40.2	0.104
A3-2	17.2	0.207	42.6	0.066	78.7	0.236
A3-3	6.9	0.014	8.7	0.006	29.5	0.084
A4-1	37.2	0.281	35.1	0.055	16.2	0.027
A4-2	28.4	0.068	13.6	0.017	26.8	0.033
A4-3	8.8	0.049	7.3	0.011	10.5	0.022
A5-1	55.1	0.595	51.7	0.105	63.1	0.211
A5-2	41.4	0.278	64.4	0.143	55.0	0.217
A5-3	8.7	0.043	29.7	0.053	12.5	0.028
A6-1	53.2	0.406	26.8	0.040	50.4	0.109
A6-2	23.8	0.086	36.8	0.035	35.2	0.101
A6-3	4.3	0.016	10.8	0.014	10.8	0.026
A7-1	29.9	0.194	24.4	0.068	22.9	0.044
A7-2	24.6	0.105	67.9	0.179	32.1	0.125
A7-3	6.0	0.014	34.6	0.046	10.3	0.017

Analysis of droplet distribution uniformity

As shown in *Figure 8*, the three UAV were all carried out under the best operating parameters. It can be seen from *Figure 8*, the deposition distribution of droplets in each collecting point is different under different operating parameters. The deposition amount and uniformity of each collecting point are relatively good on the whole, and the droplets of each collecting point are relatively good. The coefficient of variation is 37.37%, the coefficient of variation is 69.34%, and the coefficient of variation is 110.88%. The coefficient of variation reflects the droplet deposition uniformity of the UAV, and the results show that the droplet distribution uniformity of the single rotor UAV is better than that of the multi-rotor UAV as a whole.

It also can be concluded that the drift on the right side is larger than that on the left side, and the drift is smaller when the operating speed is 5 m/s. It can be seen from that there is little difference in droplets deposition data collected from at different operating parameters. Under different operating parameters, it can be concluded that the single-rotor UAV has a single and stable downwind field and less ground loss and drift.

The wind field of S40 single-rotor plant UAV is relatively stable. It has a strong penetrating and a better droplet deposition and uniformity. The six nozzles of M8A eight-rotor UAV are arranged under the fuselage, and there is disturbance between the wind field, so the distribution of turbulence is not uniform. The M23 four-rotor drone with one nozzle under each rotor, has enough atomization and less deposition.

Figure 8. Plant protection UAV deposition layout

Comparative analysis of penetration of fog droplets

As can be seen from *Figure 8*, the density of droplets in each sampling point of soybean canopy can reach 15/cm². As shown in *Figure 9*, the distribution of droplets in the upper, middle and lower canopy of three UAV can be visualized to show the penetration of droplets in different UAVs.

Figure 9 shows when the S40, M23, and M8A UAVs are operated, droplets can reach the lower layer of the soybean blade. The density of droplets deposited in the lower layers decreased gradually. The density of droplets in the middle layer of soybean decreased by 14.75% compared with that in the upper layer, and that in the lower layer decreased by 71.85% compared with that in the middle layer. During the spraying operation with M23 electric four-rotor UAV, the droplet density of the middle blade is higher than that of the upper layer and the lower layer, and the deposition density of the middle layer is higher than that of the lower layer. The density of droplets in the lower

layer was 60.77% less than that in the middle layer. During the spraying operation with the M8A electric eight-rotor UAV, the droplet deposition density of the middle layer blade was 10.27% higher than that of the upper layer blade, and the lower layer was 66.67% lower than that of the middle layer.

Figure 9. Droplet distribution in soybean canopy

Conclusions

The main parameters of S40 electric single rotor, M23 electric four rotor and M8A electric eight rotor UAV are briefly introduced. The spray experiments in the soybean pod period are carried out with these models.

Under different operating parameters, height and velocity have significant influence on the deposition and distribution of droplets. As the wind field of the single-rotor plant protection unmanned aerial vehicle is single, droplets can reach the bottom of the soybean canopy under different working parameters. At different speeds and heights, the deposition amount and distribution uniformity of droplets are different. The deposition density of upper, middle and lower canopy droplets of soybean has certain regularity. The results of droplet deposition show that the droplets of single rotor and multi-rotor UAV can reach the lower part of soybean canopy, and the density of droplets can be more than 15/cm². The single rotor UAV has a single wind field, uniform distribution and strong penetration.

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REFERENCES

- [1] Chen, S. D., Lan, Y. B., Li, J. Y., Xu, X. J., Wang, Z. G., Peng, B. (2017a): Evaluation and test of effective spraying amplitude of plant protection UAV during aerial spraying. – Journal of Agricultural Engineering 33(7): 82-90.

- [2] Chen, S. D., Lan, Y. B., Li, J. Y., Zhou, Z. Y., Liu, A. M., Xu, X. J. (2017b): Comparison of effects of aerial spraying and artificial spraying on rice application. – *Journal of South China Agricultural University* 38(4): 103-109.
- [3] Chen, S. D., Lan, Y. B., Zhou, Z.Y., Liao, J., Zhu, Q.Y. (2017c): Effects of spray parameters of small plant protection UAV on droplet deposition in orange canopy. – *Journal of South China Agricultural University* 38(5): 97-102.
- [4] Gong, Y., Fu, X. M. (2008): Aeronautical application technology in modern agriculture. – *Agricultural Equipment Technology* 34(6): 26-29.
- [5] Guo, Y. W., Yuan, H. Z., He, X. K., Shao, Z. R. (2014): General situation and prospect analysis of agricultural aviation plant protection development in China. – *China Journal of Plant Protection* 34(10): 78-82.
- [6] Jin, X., Dong, X., Yan, X. J., Yan, H. R. (2016): Design and test of target spray system for 3WGZ-500 sprayer. – *Journal of Agricultural Machinery* 47(7): 21-27.
- [7] Liu, K. X. (2015): Development status of agricultural aviation industry in Russia, Japan and South Korea. – *Age Agricultural Machinery* 42(7): 169.
- [8] Lou, S. Y., Xue, X. Y., Gu, W., Cui, L. F., Zhou, Q. Q., Wang, X. (2017): Research status and trend of Agricultural Plant Protection Unmanned aerial vehicle. – *Agricultural Mechanization Research* 39(12): 1-6, 31.
- [9] Qin, W. C., Xue, X. Y., Zhou, L. X., Zhang, S. C., Sun, Z., Kong, W., Wang, B. K. (2014): Effect of spray parameters of unmanned helicopter on droplet deposition distribution in maize canopy. – *Journal of Agricultural Engineering* 30(5): 50-56.
- [10] Xu, Y., Xiao, Y. J., Liu, J. H., Zhou, J. S., Song, X. Q., Dai, X. H. (2017): Impact of drones on agricultural modernization. – *Agricultural Services* 34(16): 43.
- [11] Yang, H. Q. (2010): Analysis and discussion on the current situation of soybean industry in China. – *China Seed Industry* 4: 18-20.
- [12] Yang, W. Y., Yong, T. W., Ren, W. J. (2008): Develop industry soybean, revitalize soybean industry. – *Soybean Science* 27(1): 1-7.
- [13] Zhang, F. S. (2007): Study on the Effect of Plant Protection on Grain Production Safety in China. – *Fujian Agricultural and Forestry University, Fujian*.
- [14] Zhang, S. C., Xue, X. Y., Qin, W. C., Xun, Z., Ding, S. M., Zhou, L. X. (2015): Simulation and experiment of N-3 type agricultural unmanned helicopter's airborne application drift. – *Journal of Agricultural Engineering* 31(3): 87-93.
- [15] Zhao, H., Song, J. L., Zeng, A. J., He, X. K. (2009): Correlations between dynamic surface tension and droplet diameter. – *Transactions of the Chinese Society for Agricultural Machinery* 40(8): 74-79.