Effect of working parameter on droplet deposition in pumpkin top dressing using multi-rotor UAV

XIE Jingxin\textsuperscript{13}, HE Changzheng\textsuperscript{2}, Yao Limin\textsuperscript{5}, ZHANG Liang\textsuperscript{13}, DAI Sihui\textsuperscript{2}, LI Ming\textsuperscript{345*}, Zhang Wei\textsuperscript{1*}

\textsuperscript{1}College of Mechanical and Electrical Engineering, 410128, Hunan Agricultural University, Changsha, China
\textsuperscript{2}College of Horticulture, 410128, Hunan Agricultural University, Changsha, China
\textsuperscript{3}Hunan Agricultural Equipment Research Institute, 410125, Changsha, China
\textsuperscript{4}Hunan Agricultural Aviation Advanced Technology Engineering Technology Research Centre, 410000, Changsha, China
\textsuperscript{5}Shandong University of Technology, 25500, Zibo, Shandong, China
\textsuperscript{*}Corresponding author: liming@hunaas.cn, zhangwei@hunau.edu.cn

Abstract. With the wide utilization of UAV in agricultural experiment and field management, plant protection UAV became a highly usage equipment for famers. Topdressing for pumpkin is important, when pumpkin fruit are expanding. It is difficult for farmers and other spraying machines to work on the farm, because all the fields is covered with leaves and stalks. A field test were launched to explore UAV working parameters on pumpkin topdressing, and distribution of droplets on face or back leave were measured to reflect the spraying quality and quantity of machine. During filed experiment, parameters of each flight was set by auto-flight system, and flight speed was stable. Through field experiment and data analysis, it was found that when the flying height was 2.5 m and the flying speed was 3 m/s, the total amount of droplet deposition reached the maximum, and the droplet attachment level on the back leaves was the highest. This parameters could be a guidance when using UAV for topdressing in pumpkin or other kinds of crops.

1. Introduction
Pumpkin has been planted for more than 500 years, China has become the world’s largest producer and consumer [1]. It is one of the important vegetable crops, rich in vitamins, proteins, oil et.al, which are used in boosting body immunity and reversing symptoms of malnutrition [2]. During its growth, 3 or 4 times of topdressing were needed [3]. However, it was hard for manual applicators and spraying machines to operate in fruit expansion stage [4]. Labors or trackers will destroy stalks, and reduce productions. As an integral part of agricultural aviation [5-6], unmanned aerial vehicle for plant protection is a fast and efficient spraying operation machine that has emerged in recent years [7]. Because of its strong flexibility and lower damage rate on crop, it become widely used. It also have advantages of lower labor intensity, less exposure to pesticides and no acquirement of specialized landing site [8].

Many researchers have studied plant protection operation using UAV, like rice [9], citrus [10] et al. The flight parameters of UAV and droplet distribution on crops got most research hotspots. Wang et al.
tested the spatial distribution of droplets during the application of unmanned plant protection machine, used the data to analyze the level of droplet deposition during operation, and found that there were many distributions of lower wind direction and bottom droplets. Zhang et al. [12] studied droplet deposition on Citrus with UAV working at different heights. Results showed that the UAV performed better when working at a 1.0 m working height, and average droplet deposition densities were higher than working on 1.5 m height. Tang et al. [13] tested 3 different working height on citrus tree by using four-rotor UAV, according to the droplet coverage rate and droplet density results, spraying performance at 1.2 m is better than that at 0.6 m and 1.8 m. Studies indicated that working heights is one of the important parameter which affect spraying quality of UAV. However, working parameters of UAV were difference, when the crops changed. It is hard to achieve uniform droplets distribution for pumpkin, due to foliage of pumpkin is quite large and stem growth direction is uncertain. Droplet deposition on surface of leaves is quite related to leaf area, geometric properties of crop, operation parameters and nozzle type when using UAV. In this paper, we explored the effects of working parameters and droplet distribution on surface of pumpkin leaves using a UAV.

2. Material and methods

2.1. Experiment site and conditions
The test site is located in the 10th team of Jianxin Farm, Junshan District, Yueyang City, Hunan Province, China. Experiment field is divided into 10 plot, each plot is 9 m wide and 7 m length and have a 1 m wide isolation strip between two plots, as show in figure 1. Field test started from June 13\textsuperscript{th} to 15\textsuperscript{th}, 2019, the weather was cloudy and sunny, and temperature is between 21 °C to 28 °C.

![Fig.1. test plot and field](image)

2.2. Operation parameter selection of UAV
Working height (flight height to canopy) and speed was considered to be the important parameter that effect the efficiency or quality of spraying tasks by using UAV. As former studies suggested that different droplets distribution will obtained, when the UAV flight at difference parameters. The single factor test was designed to find better working parameters in pumpkin top dressing, and 2 m/s, 3 m/s, 4 m/s were chosen for flight speed; 1.5 m, 2 m, and 2.5 m were set for flight height.

2.3. Experiment device and instruments
The six-rotor UAV (3WX6-10, Hunan Soar Star Aviation Technology Co., Ltd., Changsha, China) was used in this experiment and its key parameters are as follows: the container capacity 10 L, spray swath 2.0-4.0 m, working height 1.0-3.0 m, particle size ranges from 80 μm to 120 μm. There are four conical nozzle vertically arranged under four rotor wing arms, and its spray volume is 1100-1300 mL/min. Both working height and operating speed can be adjusted with experiment requirements.

The water sensitive paper was used to detect droplet density and particle size during test process, it was placed on surface and back of leaves to collect the droplet. When tests were done, these papers were gather and put into a sealed bag. Then, it will be scanned into image and processed by the droplet analysis software (Chongqing Liliushanxia Plant Protection Technology Co., Ltd., Chongqing, China). The data of droplets are as follows: Total droplet deposition, deposits density, coverage, and sampling area.
3. Results and Discussions

3.1. Working height and speed

Table 1 shows the droplet distribution results of UAV spraying on the pumpkin at different working height and speed. It not only reflects droplets distribution on the surface and back of leaves, but also reflects the influence of different working height and speed on droplet deposition.

| Working height/m | Total deposition of leaf surface/droplets | Total deposition of leaf back/droplets | (front/back) deposition amount/droplets·cm⁻² |
|------------------|-----------------------------------------|--------------------------------------|---------------------------------|
| 1.5              | 64                                      | 175                                  | 7.29/19.93                      |
| 2                | 151                                     | 146                                  | 17.2/16.63                      |
| 2.5              | 127                                     | 216                                  | 14.7/24.61                      |

The results of statistical analysis indicate that general trend of distribution increased with working height, and different working speed has big difference on total droplet deposition. When working height was 2.5 m and working speed was 3 m/s, the droplet density on surface and back of leave reached the highest level. The deposition on back of leave is the key value, because of fertilizer will have better assimilate by crops at back of leave.

3.2. Droplet distribution at different part of test plot

In the field test, UAV working trajectory and spray pattern was very significant, it will effect droplet deposition in whole farmland. According to the installation of nozzle on the UAV, showed in figure 2, and four spray booms were installed on four rotor arms. Nozzles at two sides of spray pattern have no overlapping areas, it will cause irregular spray deposition. An experiment was started to explore the difference of centre part and side section droplet deposition in the pumpkin field. The working height of the UAV are set to 2.5 m, flight speed is set to 3 m/s, and the test is repeated five times. The sampling position is located at the middle of the test block and at two side.

The droplet deposition results from the two sides and centre part of plots showed that, at the centre of trajectory, the amount of droplets and droplet density is at the highest level. Figure 3 showed that, the surface of leave obtained more droplets than back of leave, it caused by centre wind filed that generated by the UAV. Droplet VMD was had a stable performance in operation process.
4. Conclusion and Future work
The UAV spraying experiments were conducted to make clear the better working parameters on pumpkin top dressing, and found difference in droplet distribution at centre and side of plots. The results showed that:

1) The UAV spraying could obtain better droplet distribution at 2.5 m working height and 3 m/s working speed, which resulted in larger deposition density, even droplets diameter.

2) At centre part of UAV spraying trajectory, better spray pattern and droplet distribution will be gained and side part should be improved by good trajectory planning.

The experiments demonstrated the effects of working parameter on droplet distribution, and proposed that trajectory planning will effected side part droplet distribution in UAV spraying. There are remain some disadvantages in the fields test, such as large droplets diameter, ignored part of agronomic measures, and next time, we will integrate agronomic measures to improve droplet distribution.

Acknowledgements
This article was supported by The National Key Research and Development Program of China (2018YFD0201200) and The Key Research and Development Program of Hunan (2018GK2013), the author is very grateful to Hunan Soar Star Aviation Technology Co., Ltd. for providing plant protection unmanned aerial vehicles and related materials.

References
[1] CSY, 2017. China Statistical Yearbook. China Statistical Publishing House, Beijing 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016.
[2] Ahmad G, Khan A A. 2019. Pumpkin: Horticultural Importance and Its Roles in Various Forms; a Review. Int J Hort Agric, 4(1):1-6.
[3] Su Jian-wen, et al. 2010. Status and Developmental Strategies of Pumpkin Industry in Hunan Dongting Lake District. Hunan Agricultural Sciences, 1:90-92. (in Chinese)
[4] Li Bao-peng, et al. 2014. Open field pumpkin field management technology. Modern Agriculture, 1:12-13. (in Chinese)
[5] Li Yan-ting, et al.2009. Advances in Study on Mechanism of Foliar Nutrition and Development of Foliar Fertilizer Application. Scientia Agricultural Sinica, 42(1):162-172. (in Chinese)
[6] Lan Yu-Bin, et al. 2016. Research status and development of pesticide spraying droplet size. Journal of South China Agricultural University, 37(6): 1-9. (in Chinese)
[7] Wang Bei, et al. 2017. Effects of Foliar Spraying of Water Soluble Fertilizer Containing Amino Acids on Growth of Pepper and Cowpea. Soils, 49(4):692-698. (in Chinese)
[8] Zhang Dong-yun, et al. 2014. Current status and future trends of agricultural aerial spraying technology in China. Transactions of the Chinese Society of Agricultural Engineering (Transactions of the CSAE), 45(10): 53-59. (in Chinese)
[9] Chen Sheng-de, et al. 2016. Effect of spray parameters of small unmanned helicopter on distribution regularity of droplet deposition in hybrid rice canopy. Transactions of the Chinese Society of Agricultural Engineering, 32(17), 40-46. (in Chinese)
[10] Zhang Pan, et al. 2015. Evaluation of spraying effect using small unmanned aerial vehicle (UAV) in citrus orchard. In The Sixth Asian Conference on Precision Agriculture (pp. 46-48). The Chinese Society of Agricultural Engineering. (in Chinese)
[11] Wang Chang-ling, et al. 2016. Testing method of spatial pesticide spraying deposition quality balance for unmanned aerial vehicle. Transactions of the Chinese Society of Agricultural Engineering, 32(11): 54-61. (in Chinese)
[12] Zhang P, et al. 2016 Effects of citrus tree-shape and spraying height of small unmanned aerial vehicle on droplet distribution. Int J Agric & Biol Eng, 9(4): 45-52.
[13] Tang, et al. 2018 Effects of operation height and tree shape on droplet deposition in citrus trees using an unmanned aerial vehicle. Computers and Electronics in Agriculture, 148:1-7.