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Droplet deposition and control effect of insecticides sprayed with an unmanned aerial vehicle against plant hoppers

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A B S T R A C T

A small unmanned aerial vehicle (UAV) that can spray pesticide with high efficiency and with no damage to crops is required for the timely and effective spraying of small fields and/or those in hilly mountains. The current study aimed to illuminate the influence of spraying parameters, such as operation height and operation velocity, of the UAV on droplet deposition on the rice canopy and protection efficacy against plant hoppers. Droplets of 480 g l^{-1} chlorpyrifos·(Regent EC) (at a dose of 432 g a.i. ha^{-1}, spray volume rate of approximately 15 l ha^{-1}) were collected using water-sensitive paper, and the coverage rates of the droplets on the rice canopy and lower layer were statistically analyzed. The deposition and distribution of droplets in the late stage of rice growth were closely related to the operational height and velocity of crop spraying as executed by the UAV, further affecting insect control. The spraying parameters for preventing plant hoppers were then optimized. When the spraying height was 1.5 m and the spraying velocity 5 m s^{-1}, the droplet deposition in the lower layer was maximized, and the droplets exhibited the most uniform distribution (CV = 23%). The insecticidal efficacy was 92%–74% from 3 to 10 days after spraying insecticide. Both the insecticidal efficacy and the persistence period were greater than those achieved with a hand lance operated from a stretcher-mounted sprayer (at dose of 432 g a.i. ha^{-1}, spray volume rate of approximately 750 l ha^{-1}), especially on the 5th day, indicating that UAV had a low-volume and highly concentrated spray pattern to enhance the duration of efficacy. This work offers a basis for the optimized design, improved performance, and rational application of UAV.

1. Introduction

Rice is a staple food in 39 countries, including for 2.70 billion people in Asia (Sarao et al., 2015; Sardesai et al., 2001). The productivity of rice is strongly affected by biotic and abiotic factors. Annually, approximately 52% of the global rice production is lost due to damage elicited by biotic factors, of which nearly 21% is caused by insect attacks (Brookes and Barfoot, 2003). More than 100 insect species have been recognized as pests of this crop (Heong and Hardy, 2009). The brown plant hopper (BPH) *Nilaparvata lugens* is a typical sap-sucking insect of rice and has caused considerable crop loss globally, especially in southern China. The damage that is caused by BPH usually occurs during the late stage of rice growth. At this time, leaves of the rice canopy overlap, making it inconvenient for crop spraying using a conventional land-spraying machine. Moreover, it is difficult to permeate the lower-middle parts of the rice canopy where rice plant hoppers are often found (Sheng et al., 2002). The high and stable yield of rice is thus hampered. Due to the harsh walking conditions in rice paddies, operating a land-spraying machine is very difficult and requires high labor intensity. Large-volume spraying not only leads to pesticide waste but also seriously endangers the environment and the operators (Zhang et al., 2011). Furthermore, timely application for the prevention of fast pest and disease outbreaks cannot be rapidly achieved, the consequence of which is that plant diseases and insect pests cannot be effectively prevented and controlled (Sōgawa, 1982). Therefore, special stress has been placed upon dealing with the present dilemma by improving mechanization to prevent rice pests and diseases in China (Zhou et al., 2013).

Aerial application, usually called aerial crop spraying, involves

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spraying crops with fertilizers, pesticides, fungicides, and other crop protection materials using agricultural aircraft (Lan et al., 2010). The countries that possess developed agricultural aviation mainly include the United States, Russia, Australia, Canada, Brazil, Japan, and Korea. In thinly populated areas of the United States, manned fixed-wing aircraft is the most popular form of agricultural aviation (Xue and Lan, 2013). The developmental mode of agricultural aviation in Russia, Australia, Canada, and Brazil shares the same characteristics as the United State, the main types of which are manned fixed wing aircraft and rotor helicopters. In contrast, there are many mountains and very little arable land in Japan and Korea, which are unsuitable for the use of manned fixed wing aircraft. Agricultural aviation in these area is thus dominated by small unmanned aerial vehicles (UAV). Compared to conventional agricultural aircraft, UAVs do not require a special airport and have advantages, such as good mobility (Chen and Lu, 2012; Bae and Koo, 2013). UAVs are also more adaptable for spraying at low altitudes due to geographical restrictions (Zhang et al., 2014; Lan et al., 2008; Fritz et al., 2007). Recently, the use of aviation in plant protection has developed rapidly in China (Xue et al., 2008), especially the use of UAVs to implement aerial spraying. The topography in southern China is mainly composed of paddy fields and hilly mountains. Xue et al. (2013) studied the control efficiency on rice plant hopper and *Cnaphalocrocis medialis* Guenee using UAV to spray insecticides. Compared to traditional ground-based pesticide application, the efficiency of UAV increased by more than 60 times. Meanwhile, the pesticide dose decreased by 20–30%, associated with a remarkable reduction in labor intensity. The use of UAVs provides a useful operating platform for preventing rapid outbreaks of plant and pest diseases in paddy fields and for upgrading technology for rice plant protection.

As an emerging technology, there are still a series of practical issues for UAV spraying for pest protection, such as ambiguous optimal work parameters and poor penetrability into the crop canopy, low droplet coverage ratio, and heterogeneous droplet distribution. Recent studies revealed that unsuitable spraying parameters not only impact the control effect against the insects but also cause the pesticide drift. Aerial spray drift has been studied regarding spray droplet size, application release height, nozzle configurations and weather (Xue et al., 2014; Fritz et al., 2009; Hoffmann et al., 2009; Richardson and Thistle, 2006; Tsai et al., 2005). Aerial pesticide application systems have focused on wing aircraft spraying and UAV spraying. Kirk (2007) used a PMS laser particle analyzer to measure the VMD of droplets in a fixed-wing aircraft spraying system and constructed a mathematic prediction model between droplet drift and spray parameters, i.e., droplet VMD, aircraft height, and aircraft speed. Their results showed that not only VMD but also aircraft height and speed, had a profound influence on the droplet drift. Huang et al. (2009) developed a UAV plant protection working system and found that the droplet size was intimately correlated with spray flux. Small droplets were prone to penetrate the crop canopy and to form a high coverage density, while large droplets trended to flow away from the surface of the leaf, resulting in a low coverage density.

Considerable efforts have been devoted to exploring field spray experiments based on the current situation of small UAVs in China. For example, Qiu et al. (2013) studied the distribution regularities of the droplet deposition sprayed by CD-10 UAV under the influence of flight height and velocity. A relevant model was established to clarify the interactive relationship between deposition concentration, deposition uniformity, flight height, and flight velocity. Qin et al. (2014) investigated the effect of N-3 UAV pesticide application on the droplet deposition distribution in the maize canopy. Their statistical results showed that the total deposition number of droplets on the target position was reduced to the minimum, with the largest dispersion at a working height of 5 m. The total deposition was higher at a working height of 7 m than at 5 m or 9 m, in which the dispersion of deposition droplets was minimal. Despite these preceding studies, the influences of spray manner and spray parameters by the UAV on the droplet deposition uniformity and pest control effect have not been reported.

The aims of this study were to explore the droplet deposition levels of pesticide spraying in the canopy layer of rice using UAVs, to study the uniformity of droplet distribution, and to evaluate the control efficiency during a multi-swath spraying process. The HyB-15L UAV was used to spray insecticide, and a common stretcher-mounted sprayer was chosen for comparison.

2. Materials and methods

2.1. Materials

480 g l^{-1}Chlorpyrifos·Regent EC was used as the pesticide agent was supplied by Dow Benefit Agriculture Co., Ltd., Shanghai, China. The tested rice was Liangyou 1128, the growth period of which was the heading stage. The planting spacing, planting height, and leaf area index (LAI) were 10 × 17.5 cm^2, 0.9–1.1 m, and 8 m^2 m^{-2}, respectively. The pest was the rice plant hopper (BPH).

2.2. Spraying platform and spraying systems

The type of aviation platform was the HyB-15L UAV, which was equipped with a spraying platform. The main parameters of the HyB-15L UAV are presented in Table 1. Using GPS, the accuracy of the flying height and flying velocity was controlled within 0.5 m and 0.3 m s^{-1}, respectively. The spraying platform consisted of a medical kit with a capacity of 15 L, miniature straightway pump, pipeline, spraying nozzle, and electronic control valve. Four spraying nozzles (Tee Jet 110067) were symmetrically arranged on both sides of the UAV at the same interval (450 mm), and the installing angle of the spraying nozzles was vertically downward with the spraying direction. At a working pressure of 0.3 MPa, the measured flow rate of a single spraying nozzle was 280 ml min^{-1}, and the average VMD of the droplets within 1 m of the spray nozzle was 233.5 μm. A laser particle size analyzer was used to measure the size of the droplets using water as a measurement medium. The average VMD was calculated by measuring the size of 2–3 × 10^4 droplets, and the pesticide application dosage was –20 L/hectare. To clarify the control effect, the conventional stretcher-mounted sprayer was chosen for comparison (Fig. 1).

It is a hand lance sprayer (non-air assisted) with the pump and spray tank carried separately on a stretcher. The hand lance is attached to the pump and spray tank on the stretcher by a long hose. Three persons are required to operate the sprayer, one to carry and operate the hand lance and two persons to carry the stretcher on which the spray tank and pump are mounted. The working pressure and horizontal range were 15 MPa and 14 m, respectively. The flow rate of a single spraying nozzle was –3500 ml/min, and the pesticide application dosage was 750 L/hectare.

2.3. Environmental monitoring

Measures of air temperature and humidity were deployed at heights of 0.8 m and 1.5 m, respectively, above the canopy every 5 min. To exclude the interference with spraying, the instrument (8901, Wangyitong Instrument Co., Ltd., China) was placed 10 m from the work zone to record the wind speed. Three wind speed sensors were set vertically at heights of 0.8 m, 1.5 m and 2.0 m, respectively, above the crop, and the data were collected every 60 s. The calculated average was tabulated in Table 2.