附件目录

1.代表性论文、论著

1.1 Develop an unmanned aerial vehicle based automatic aerial spraying system **(SCI)**

1.2 Droplet deposition and control effect of insecticides sprayed with an unmanned aerial vehicle against plant hoppers **(SCI)**

1.3 Drift and deposition of ultra-low altitude and low volume application in paddy **(SCI)**

1.4 美国农业航空技术现状和发展趋势分析 **(EI)**

1.5 无人直升机喷雾参数对玉米冠层雾滴沉积分布的影响 **(EI)**

1.6 Optimization and test for spraying parameters of cotton defoliant sprayer **(SCI)**

1.7 N-3 型农用无人直升机航空施药飘移模拟与试验 **(EI)**

1.8 无人机高浓度施药对水稻品质的影响 **(EI)**

1.9 N-3 型无人直升机施药方式对稻飞虱和稻纵卷叶螟防治效果的影响

1.10 专著《农用无人机 100 问》

2.重要科技奖项

2.1 中华农业科技奖一等奖

3.重要社会奖项

3.1 中国产学研合作创新奖

4.重要国际、学术机构或国际顶级学术期刊的兼职情况

4.1 副主席-国际农业工程学会（CIGR）精准农业航空分会

4.2 秘书长-中国农业工程学会农业航空分会

4.3 秘书长-中国农机工业协会植保与清洗机械分会

4.4 副主任委员-中国农业机械学会农业航空分会

4.5 副理事长-国家航空植保科技创新联盟

5.主持项目（课题）情况

5.1 国家重点研发计划项目“农用航空作业关键技术研究与装备研发”

5.2 公益性行业科研专项“植保机械关键技术优化提升与集成示范”

5.3 科技部成果转化项目“新型系列均匀施药技术装备中试与示范”

5.4 农业行业标准制定与修订项目“农用遥控飞行器安全技术要求”

5.5 农业行业标准制定与修订项目“农用遥控飞行喷雾机试验方法”

5.6 江苏省自然基金项目“旋翼无人机施药雾滴运动行为特性研究”

5.7 江苏省农业协同创新项目“低空低量航空植保关键技术及装备研发”

5.8 江苏省国际交流与合作项目“中美航空安全施药技术合作研究”

5.9 江苏省自主创新项目“果园高效植保机械关键技术研究与装备创制”

6.专利情况

6.1 基于模型的直升机航空施药飘移预测方法，ZL 201210411015.8，发明专）

6.2 植保无人机喷洒二相流场室内模拟测试平台及方法，ZL 201510051943.1，发明专利

6.3 一种电磁泵注入式混药系统，ZL 201010298655.3，发明专利

6.4 一种水稻插秧机施药器及施药控制方法，ZL 201310644118.3，发明专利

7.标准制定情况

7.1 农业行业标准《植保无人飞机质量评价技术规范》（NY/T3213-2018）

7.2 机械行业标准《植物保护机械通用试验方法》（JB/T9782-2014）

7.3 机械行业标准《喷雾式动物防疫消毒机技术条件》（JB/T12451-2015）

8.文献检索报告

1. 代表性论文、论著

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Original papers

Develop an unmanned aerial vehicle based automatic aerial spraying system

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ABSTRACT

To perform plant-protection operations, an unmanned aerial vehicle (UAV) based automatic control spraying system was designed in China. The system used a highly integrated and ultra-low power MSP430 single-chip micro-computer with an independent functional module. This allowed route planning software to direct the UAV to the desired spray area. The test results of route precision showed that in a 3–4 m/s crosswind, route deviations were around 0.2 m. The result of multiple-spraying swath uniformity tests showed a minimum coefficient of variation of 25% when flying at a height of 5 m with a spraying swath of 7 m and a wind speed of 0–2 m/s. When the spraying swath was 9 m or 5 m, the coefficients were 34% and 41%, respectively. Spray uniformity for these UAV tests were superior to the Standard Requirement for ultra-low volume spraying variation coefficient, 60%.

1. Introduction

Aerial spraying by unmanned aerial vehicles (UAVs) has a large application potential in many areas in Asia, including Korea and Japan, where most fields are small-scale or fragmented. By the end of 2012, the application area for UAV spraying in agriculture and forestry was a hundred thousand hectares in Japan (JAAA, 2014). Yamaha Corporation (Japan) has pioneered the concept of unmanned helicopters for agricultural applications. Yamaha helicopters have been adopted as a research platform by many countries worldwide. However, the export of Yamaha helicopters was banned in 2007 to protect their technology from being used by others.

During the last decade, China has systematically carried out research on rice, maize and wheat diseases and insect prevention using UAV spraying technology under the support of National Science and Technology projects. For example, Xue et al. (2011, 2013) studied UAV (model N-3, Nanjing Research Institute on Simulation Technique) control efficiency for rice plant hopper and cnaphalocrocis medinalis guenee. Zhang et al. (2012) used the pesticide analogue to investigate the droplet deposition characteristics of the PH642 unmanned helicopter. Gao et al. (2013) conducted research on NF-811's control efficiency for wheat midge and maize borer. However, little literature is available on automatic spraying systems based on UAV platforms. The authors have conducted research to develop a fully autonomous helicopter platform for aerial application.

In order to improve the working efficiency, spraying systems on UAVs should be configured to deliver high-concentration and low-volume sprays. Spray rates for UAV systems are generally 1–2 L/ha, which is 25–50 times lower than conventional spray application systems. However, due to the use of higher concentration sprays, applicators should ensure that there is no excessive overlap or gaps in the spray pattern in order to avoid causing phytotoxicity or deficient prevention. With the small droplets used in low-volume pesticide spraying, UAVs should fly low at a height of 3–5 m in order to avoid spray drift. Moreover, UAV spraying should ensure the stability of low-altitude flight and precise control of the spray swath. The accuracy of flight control has been improved through the optimization of automatic guidance systems (Budiyono and Wibowo, 2007; Raptis and Valavanis, 2011). The constant-level and flight stability of the UAV at low altitude has been improved by adopting control algorithms such as PD (Merheb and Noura, 2012) and Kalman filter (Bar-Shalom et al., 2001; Rullán-Lara et al., 2011).

Spray systems for UAVs must be designed carefully to ensure spraying accuracy. Huang et al. (2009) developed a UAV spraying platform and carried out simulation spraying tests. The developed spray system has the potential to provide accurate, site-specific crop management when coupled with a UAV system. Zhu et al.

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(2010) designed an UAV precision spray system based on pulse width modulation (PWM), which has promise as a high precision technique for spray application systems. Zhou et al. (2011) used electric centrifugal nozzles and an aerial irregular wave-prevention pesticide tank to improve the spray quality from a UAV. Ru et al. (2012) tested a UAV with a spray system which was controlled remotely from the ground.

Global Positioning System (GPS) navigation has been widely available for precision aerial applications. Spraying from a UAV following a preplanned flight route is an important way to ensure the stability of low-altitude flight, the spraying swath seamless overlapping, and consistent spraying quality. At present, this technology has been widely applied on agricultural aviation manned aircraft and it has also been applied to other technologies such as precision agricultural UAV aerial photography (Xue and Lan, 2013; Yu et al., 2009). However, there are only a few research publications on applying both navigation and automatic spraying control technology on UAV spray application platforms. Therefore, in this study a UAV system has been designed to accommodate a spray system, which was interfaced with electronic control systems to activate spray releases based on the GPS coordinates and pre-programmed spray locations. This system has route planning and real-time display, and can be configured for autonomous flight following flight plans with automatic control of the spray system.

2. Materials and methods

2.1. Unmanned aerial vehicle (UAV)

The UAV system, named N-3-type, includes a helicopter and a ground control system (Fig. 1). The helicopter is equipped with a flight controller, gyro-scope, GPS receiver, image transmitter, telemetry transmitter, altimeter, heading sensor, and spray system. The ground control system consists of a telemetry receiver/display system and a remote-control transmitter. The N-3-type was an improvement over the original Z-3 type UAV (Xue et al., 2013). A force-air engine cooling system was employed to solve the cooling problem of the engine under the conditions of low-altitude and low-speed flight. High-precision vertical gyroscopes (VG400, Moog Crossbow, Inc., Milpitas, CA) were used as the sensors for aircraft heeling angle, pitch angle and 3D positional velocity. The magnetic heading sensor (HMR2300, Honeywell, Morristown, NJ) was adopted to correct the error created by rapidly changing flight directions. A pressure altimeter (HPA200, Honeywell Inc., Morristown, NJ) was used to measure and record the flight height of the UAV and a position sensor (OEM4-G2GPS, NovAtel Inc., Calgary, Canada) was used to determine the position of aircraft. The control variables were calculated based on PID and Kalman filtering algorithms. Flight control system and loop control schematic diagrams are shown in Fig. 2. The interface used was RS422 serial. With the use of these new components, this new UAV system was improved in many ways, including the stable accuracy RMS of pitch angle and tilt angle were smaller than 2°, the stable accuracy RMS of yaw was less than 5°, and the RMS of stability of height was less than 1 m. The main parameters of the N-3-type UAV spraying operation were: a remote control distance of 10 km, a height of 3–7 m, a flight speed of 3–6 m/s, a tank capacity of 25 kg, and two centrifugal rotary atomizers. The spray volume of each atomizer was 0.6–1 L/min.

2.2. Design of the spray control system based on GPS automatic navigation

2.2.1. System structure and operation principle

The GPS-based automatic spray control system included the flight control system, the task link, the route planning system and the spray control system (Fig. 3). The flight control system which included FMU (Flight Management Unit) and data link was semi-integrated with the spray control system. The FMU was an original part of the UAV. Based on spraying application, the data link which included coordinate transformation, waypoint calculation and communication protocol was designed into the chip PC104. The data link sent planned route data to FMU to control the flight, read the position sensor data to calculate spraying parameter, then sent control command to the spray control system. At the same time, the data link read the spray control system feedback to communicate to the ground station via the radio.

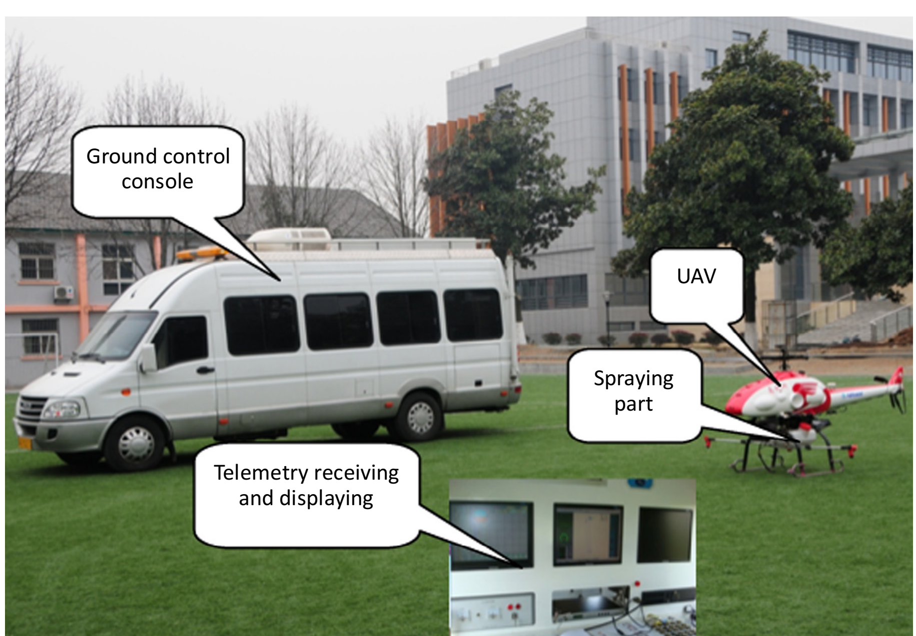


Fig. 1. N-3 type of spraying helicopter system structure diagram.

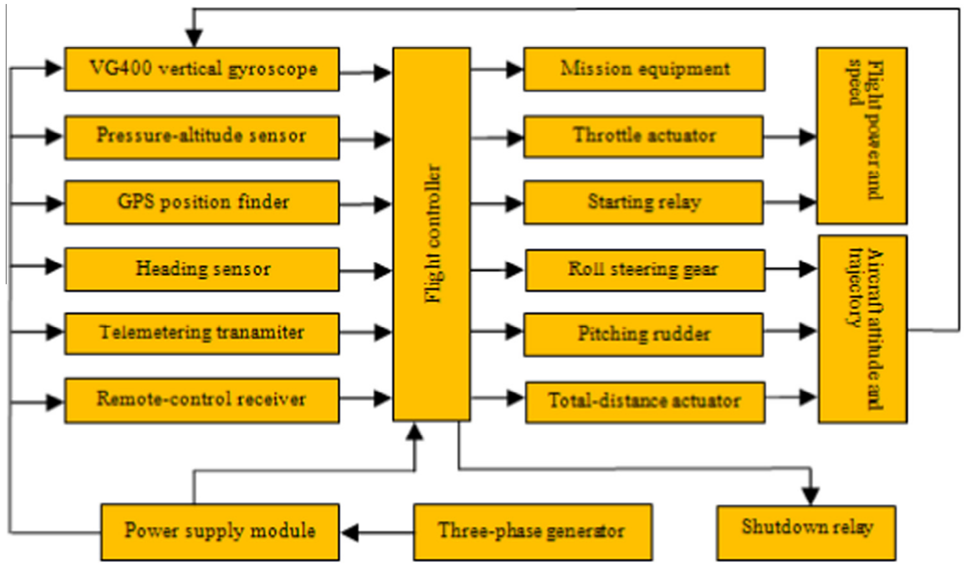


Fig. 2. UAV flight control system chart.

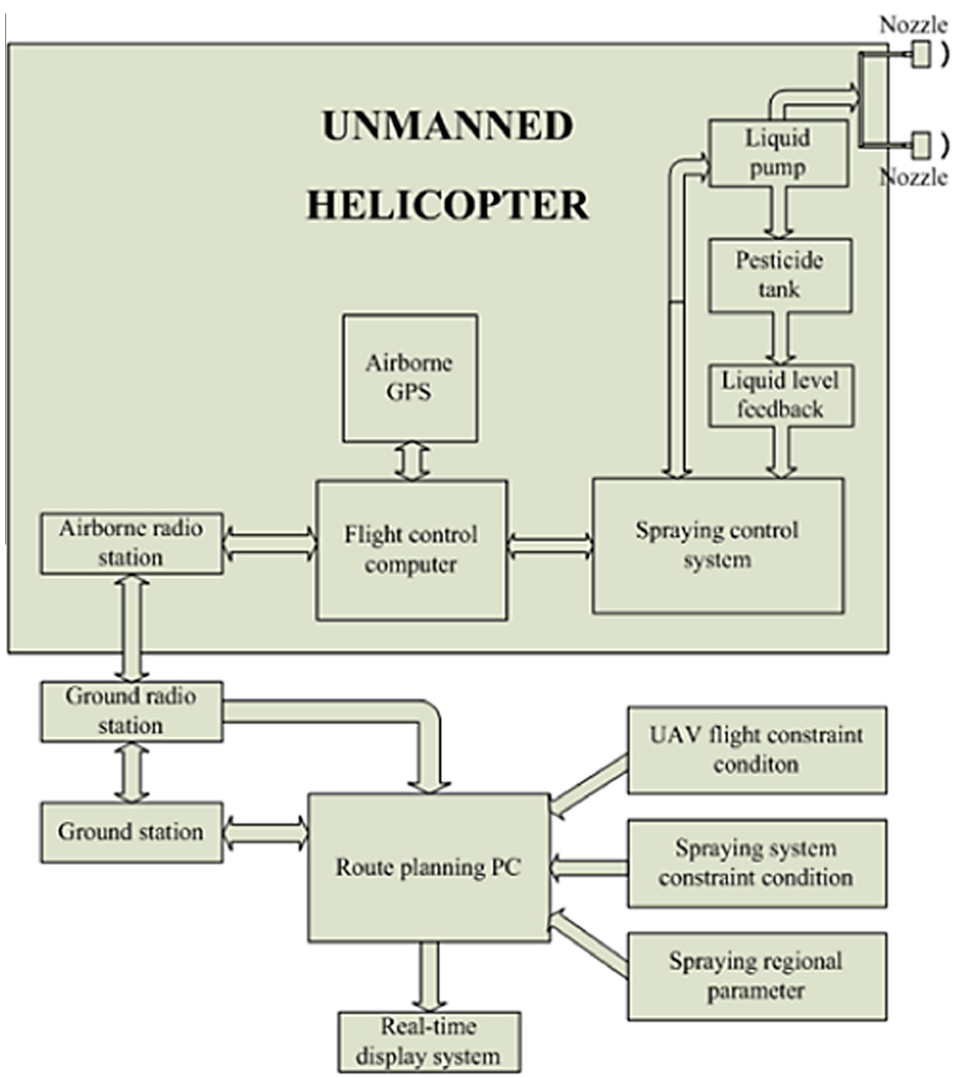


Fig. 3. Spraying control system structure of N-3.

Before spraying, GPS waypoint and spraying control point information were sent to the ground station through the upstream port of the route planning system. After the UAV received the program-controlled instructions sent to data link by the ground station, it followed the predetermined route automatically. During the process of spraying, the UAV controlled the aircraft according to the predetermined GPS coordinates and sent a separate spraying control signal to the spray system. The spray system received the spraying control signal which started and stopped the work with feedback of the real-time status of the spray system to the host computer. The host computer returned the real-time GPS information and the status information of the spray system during flight back to the ground station via telemetry channels. On the monitor of ground station, the software interface displayed the real-time spraying status and the flight path.

2.2.2. Spray control system design

The spray control system was installed on the UAV and used to carry out the precise control of the spray equipment. The spray control system consisted of a main control circuit, a communication module, a feedback module, a signal processing module and a power transmission module (Fig. 4). The main control circuit

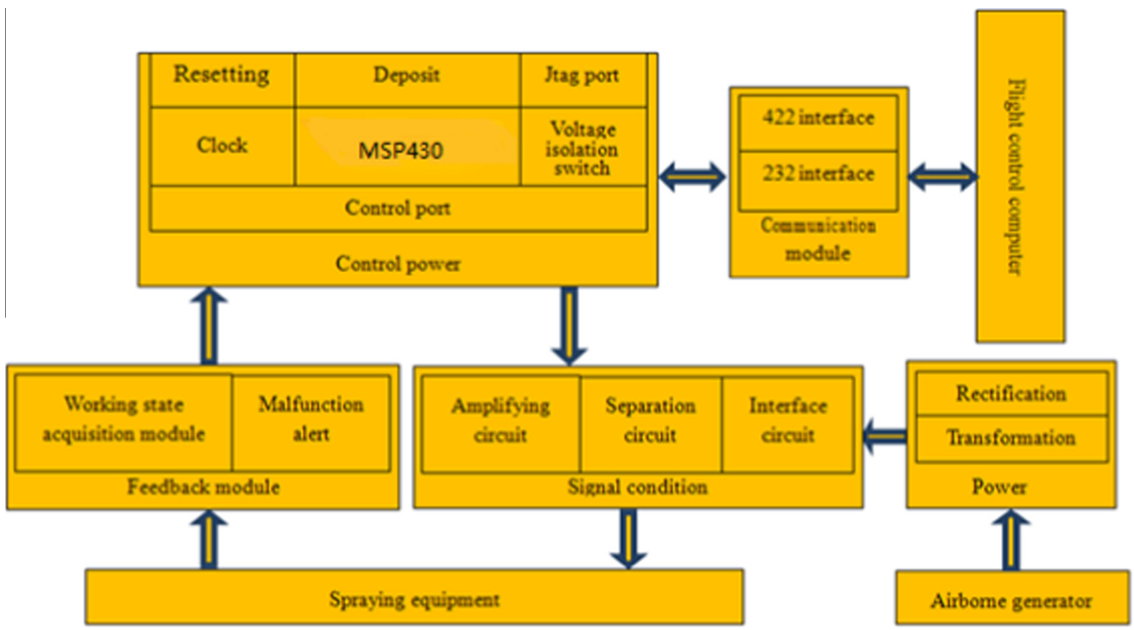


Fig. 4. Spraying control system structure.

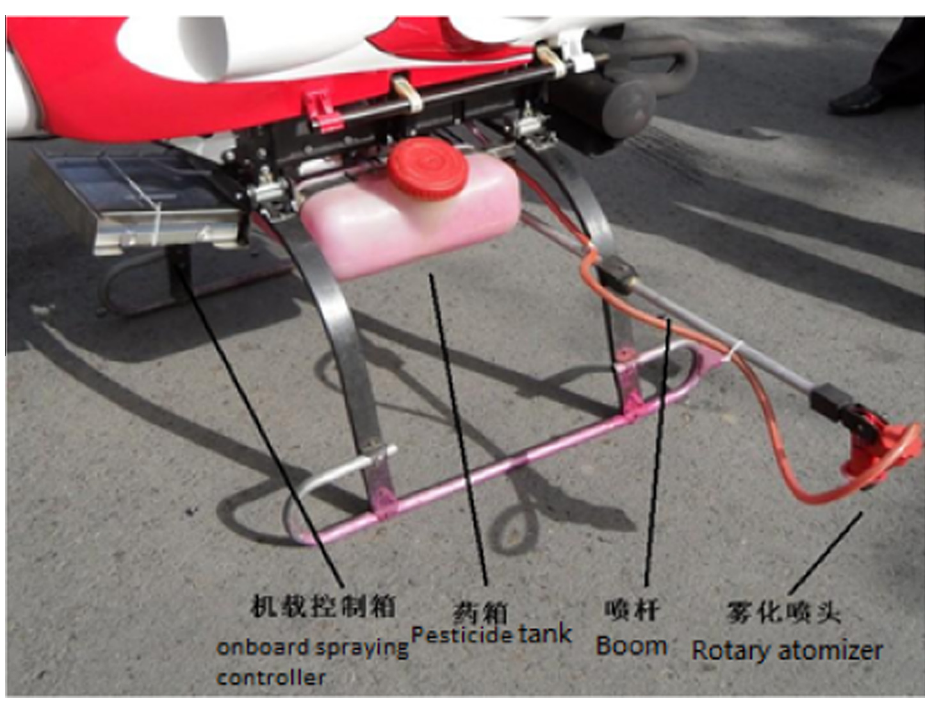


Fig. 5. Onboard spraying system.

included a single-chip microcomputer (MSP340149, Texas Instruments, Inc., Dallas, Texas), a reset circuit, a memory module, a clock module, a Jtag interface, and a 3–5 V voltage converting module. The reset circuit used GND port communication with a DVss port of a single-chip microcomputer and sent the reset command to the single-chip microcomputer to prevent a program runaway (Fig. 5).

The memory module and the clock module coordinated recording the working status of equipment in-flight as the basis for data analysis. The communication module served as the auxiliary communication terminal and main control circuit to connect the flight control host computer, transmit the spraying control signals to the main control circuit and accept the spraying system status information fed back by the main control circuit. The processing module communicated with the main control circuit and spraying equipment, accepted the real-time position information transmitted for the specified spraying sites and GPS, sent out the spraying control signal and provided the signal for the spray equipment after the signal was amplified into an electric signal to control the work of spraying components. The signal output terminal of feedback module was connected with the feedback information input terminal of the main control circuit and fed back the spray system status and liquid level information to the main control circuit. The power transmission module rectified and converted the voltage provided by the airborne generators and distributed them to the other modules (Table 1).

Table 1
Parameters of onboard spraying controller.

Items		Parameters
Total rated power (W)		60
Response time (s)		⩽0.3
Supply voltage (V)		25–30
Output (liquid pump)	Voltage (V)	16–24
	Power (W)	20–35
	Current (A)	1.1–1.8
Output (rotary atomizer)	Voltage (V)	5–12
	Power (W)	5–8
	Current (A)	0.2–0.5

2.3. Software design

Matlab (MathWorks Co., Natick, MA) was used to create the route planning software for the UAV system. The working principle of the route planning software was to collect GPS coordinates of the field boundary, connect all the coordinates into a region in

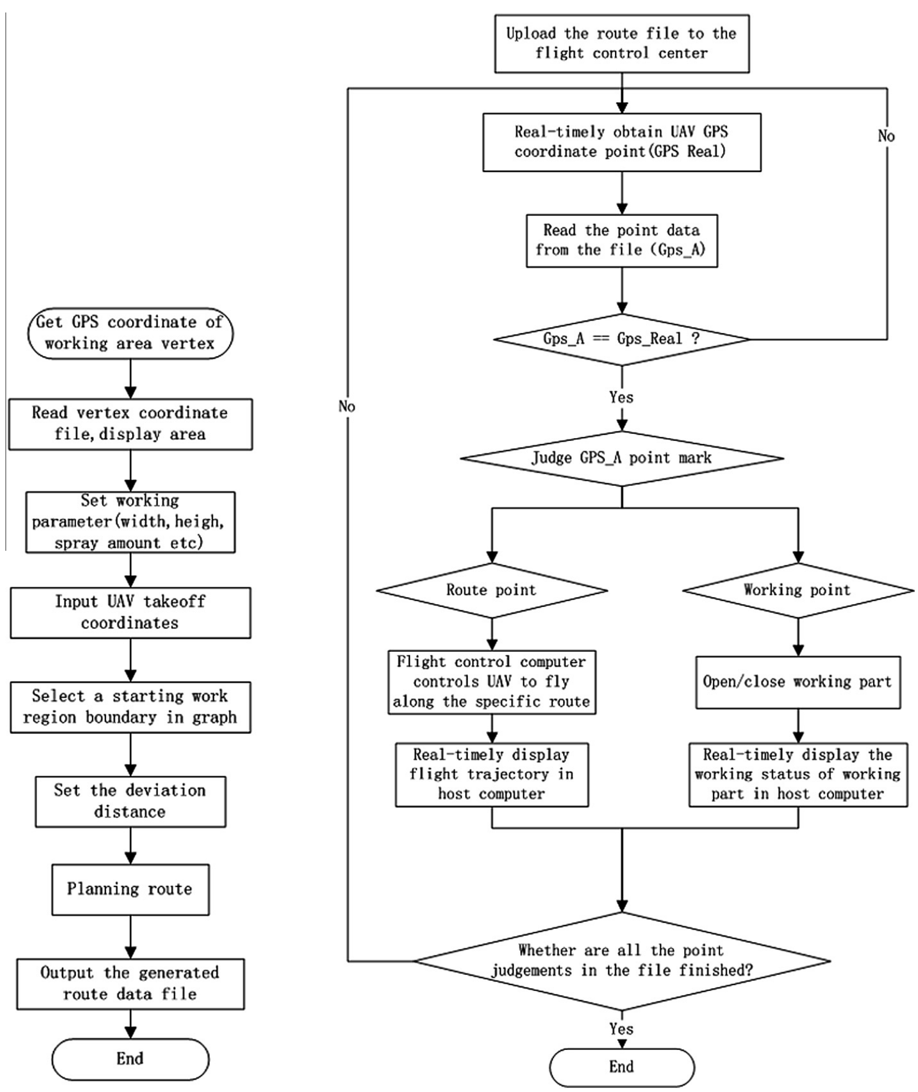


Fig. 6. Control system software flow chart.

certain order, establish GPS coordinate axis in this region and calculate the fixed coordinate of various points in the region. According to various factors, such as spray system spray swath, loading quantity of pesticide, quantity of flow, spraying time, flight velocity, and flight duration, several routes were calculated. Then, based on Bayes theorem, the best route was selected by weighted value. If the working area was very large and needed more than two flights, the final spraying location of current flight was recorded as the initial coordinates of the next flight. The standard earth model used for GPS coordinates was the WGS-84 coordinate system as issued by US Department of Defense. Usually, when GPS equipment is used to determine a point on the surface of the earth, longitude, latitude and elevation are used to describe the position of this point. Because farms here are generally level or only have a small slope, the change in elevation might be neglected here. If the measured area of a farm is relatively small, a straight line is used to replace the curve line to get a very simplified calculation formula. In this simplified calculation model, it regulates that the X axis is a line along the latitudinal direction, the Y axis is a line along longitude line, and the 2-direction lines are considered to be perpendicular within a relatively small range so that all the latitude lines and all the longitude lines were mutually parallel. This method is used to convert the longitude and latitude data determined by GPS into the plane rectangular coordinates needed in a farmland planning or UAV operation. After the UAV received the program-controlled instruction, it entered into an automatic mode and the host computer system of flight control completely controlled the flight attitude of UAV, monitored the working status of the engine, the machine equipment, the flight height, and other relative operational parameters. The GPS coordinate of the UAV was constantly monitored and compared with GPS information read from the route file. In addition, the host flight control computer system carried out the transmission of information to the ground station, and controlled the remote-control receiver, the telemetry transmitter

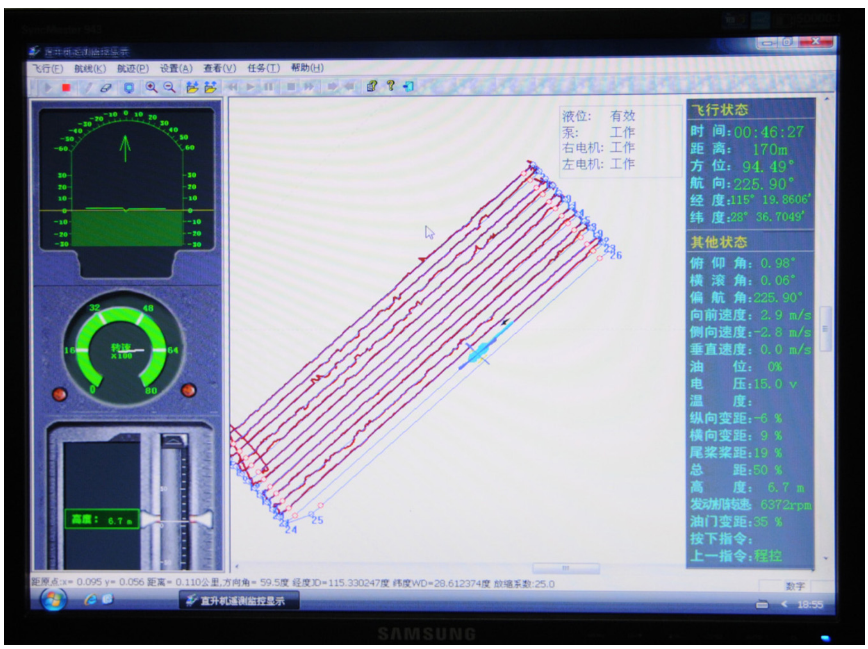


Fig. 7. Real-timely displayed route map in monitoring equipment.

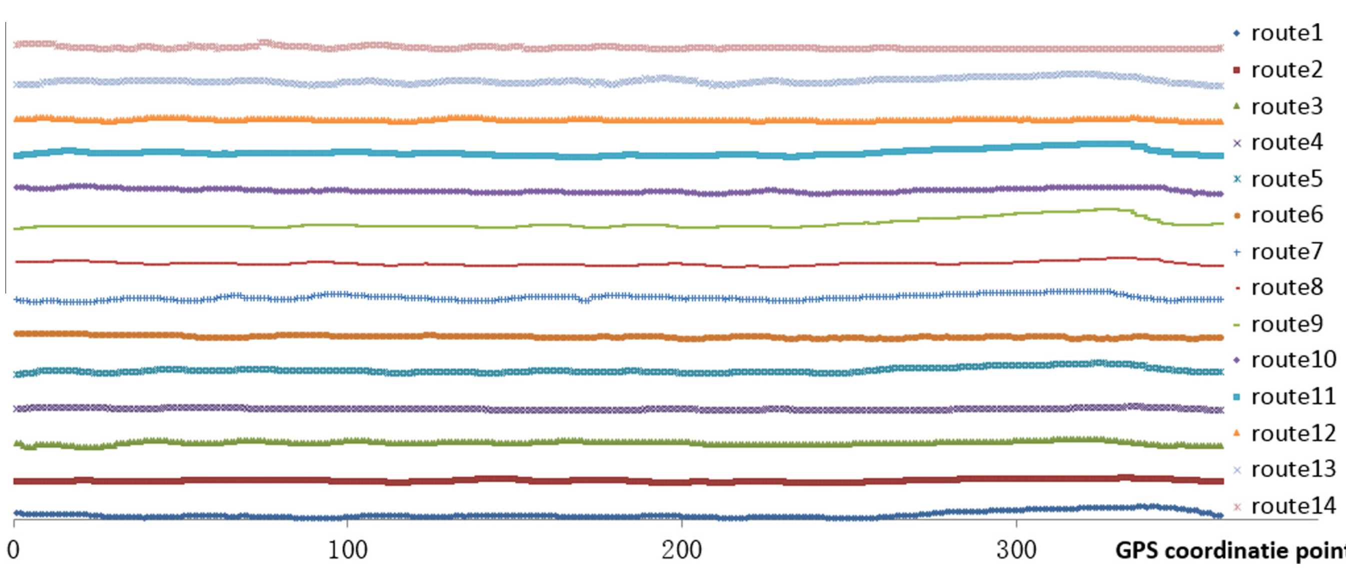


Fig. 8. Route GPS point position date diagram recorded in the ground station.

Table 2
The deviation of measured routes.

Route S/No	Maximum error	Minimum error	Average error	Mean square deviation
1	0.636315464	0.01172269	0.290652946	0.147061299
2	0.658173857	0.003685479	0.203982657	0.118737027
3	0.799482973	0.002225141	0.303557583	0.185427617
4	1.086011	0.010150915	0.275153028	0.269631317
5	0.864670632	0.0007028	0.302637326	0.190806077
6	0.888022901	6.53089E−05	0.259016951	0.234683433
7	0.489243988	0.062112244	0.28523955	0.095577492
8	1.172550841	0.000527267	0.242461397	0.229709325
9	0.967847769	0.019968612	0.501344672	0.188618601
10	1.036375906	0.000319253	0.354250497	0.234300219
11	0.979418083	0.002403523	0.457082509	0.272624961
12	0.97147915	0.001969597	0.309276493	0.216652596
13	1.245716488	0.029122419	0.41821449	0.238485573
15	0.887775102	0.002446683	0.276838663	0.189535937
16	0.932954088	0.001586328	0.164812472	0.167489661
17	1.17026422	0.002649872	0.359569123	0.241256089
18	1.036035849	0.011783662	0.372890224	0.273028399
20	1.622227359	0.000083248	0.311411567	0.338129487
21	0.52458392	0.001391913	0.150239775	0.11489542
22	0.951096956	0.000725615	0.240653872	0.227373522
23	0.657545455	0.000310282	0.307566514	0.167763593
24	0.527687192	0.001035055	0.2428826	0.145673943
25	1.6858	0.1166	0.582660574	0.245718621
26	1.2081	0.005	0.33706095	0.153720256
27	1.070972017	0.003599846	0.589118637	0.203990893
28	0.568103513	0.007409369	0.254897949	0.137602382
29	1.595041005	0.081257004	0.614699205	0.256426507
30	1.111875016	0.000947041	0.248048904	0.182590693
31	1.51811876	0.014493667	0.679977452	0.310193728
32	1.209369793	0.012768051	0.445555128	0.190750387
33	0.969465465	0.267803524	1.000827526	0.423976255
34	1.060751115	0.002355456	0.480559998	0.244964468
35	0.967661306	0.046116889	0.720532638	0.305928956
36	0.625889684	0.004553732	0.273026123	0.133153884
37	1.577345777	0.01561421	0.645439859	0.290806143
38	1.011692255	0.000195632	0.22264885	0.198827597

Test condition: wind speed: 3–4 m/s, wind gust: 7 m/s, temperature: 34°, humidity: 75%.

and the airborne receiving and sending antenna. It also sent the equipment status of the aircraft real-time, the GPS signal, and the operation status of the spray equipment to the vehicle control system. The flight control computer system also sent real-time images for display on the monitoring equipment (Fig. 6).

2.4. Spraying uniformity test

The field-spraying swath uniformity test was designed to examine the uniformity of spraying deposition under outdoor conditions. The designed flight height of was 5 m with a flight speed of 3 m/s. Three route widths (commonly called spray swath widths) were evaluated at 5 m, 7 m, and 9 m. For each width, the UAV flew three parallel lines. Mylar cards were used to collect deposition with RHB florescence tracers. The samples were analyzed using a florescence Spectrofluorophotometer (Model 95, Shanghai Lingguang Technology Co., Shanghai). The overlap spray swath inner lateral value was measured at a sample interval of 0.5 m. This process was repeated three times with pure water plus fluorescent tracer used as the spraying solution. The lateral uniformity of the spraying system within the spraying swath was described by the coefficient of variation.

3. Results and discussion

In order to verify the reliability of the system, open areas where both length and width were greater than 500 m were selected at the Anhui Mingguang UAV test base and at the Jiangxi Fengxin rice production base. The main parameters of the N-3-type UAV spray operation were a remote control distance of 10 km, a height of 3–7 m, a flight speed of 3–6 m/s, and a tank capacity of 25 kg. Each of the two centrifugal rotary atomizers had a spray volume of 0.6–1 L/min.

To evaluate the UAV, the accuracy of the flight route was determined as well as the spray uniformity with the different spray swaths.

3.1. Result of the route precision test

For the test of route precision, the designed flight height was 5 m with a flight speed of 3 m/s. Each route (i.e. spray swath) was 7 m and the length was 200 m. The real-time GPS position information during the test is shown in Figs. 7 and 8 and the deviation between the actual flight routes from the predetermined routes for the UAV are shown in Table 2. Fig. 8 shows the route test program at the Mingguang base for which there were a total of 14 routes with each route generating 360 data points based on the 0.2 s GPS reading. At the time of the tests, the crosswind speed was 3–4 m/s with a wind gust speed of 7 m/s.

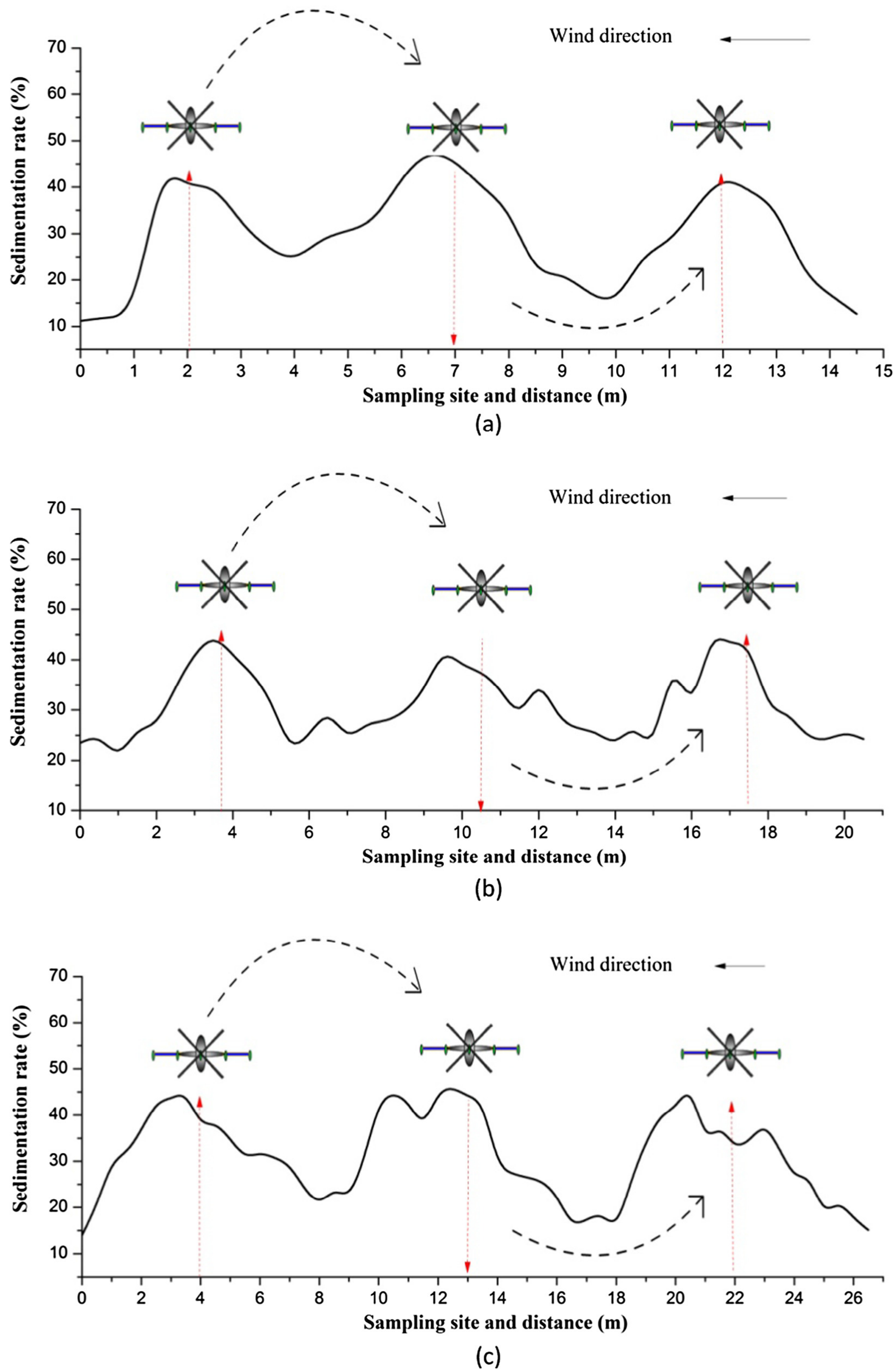
When the crosswind speed was 3–4 m/s, the deviation of the mean square roots was around 0.2 m for the 38 routes. The maximum deviation was 1.68 m with a maximum average deviation of 1 m. This showed that a small number of point deviations exceeded 1 m due to the effect of wind gusts at the time of operation.

3.2. Result of spraying uniformity test

With a wind speed of 0–2 m/s, the minimum coefficient of variation was 25% for the 7 m spray tests (Fig. 9). Although the relative sedimentation changed slightly in the overlap area between spray swaths, there was no significant difference in deposition. This showed that the deposition between spray swaths was acceptable. When the spray swath was 9 m and 5 m, the variation coefficients were 34% and 41%, respectively. These results show that the UAV system meets the Standard for ultra-low volume spraying variation coefficient, which is less than 60% as set by the Civil Aviation of China General Aviation Operation Quality and Technology Standard.

4. Conclusions

1. In order to improve the spraying quality of UAV spraying operations, an automatic navigation unmanned spraying system was developed. The system used a highly integrated and ultra-low power MSP430 single-chip microcomputer as the core control component of the system. The route planning developed for this project used the farm field boundary to plan the flight route automatically, then display the UAV position and spray system status in real-time for precision spraying.
2. The system was installed on the N-3-type unmanned aerial vehicle. The route precision examination and the multiple-spraying swath spraying performance examination in Anhui Mingguang and Jiangxi Fengxin showed that the system can be used to make low-volume spray applications. The UAV flew designated spray routes with sub-meter precision under field conditions with wind speeds up to 4 m/s. Tests revealed that a swath width of 7 m was optimal for this UAV system, and all the spraying uniformities exceeded the CAAC general aviation operation quality and technology standard.



(a) Flight height 5m; spray swath 5m; spray droplet diameter 250μm; (b) Flight height 5m; spray swath 7m; spray droplet diameter 250μm; (c) Flight height 5m; spray swath 9m; spray droplet diameter 250μm

Fig. 9. Aircraft spraying lateral swath connecting curve diagram.

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

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ABSTRACT

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.

Table 1
Characteristic parameters of the HyB-15L UAV and the stretcher-mounted sprayer.

	HY-B-15L	Stretcher-mounted sprayer
Rotor	Single rotor (Diameter = 2.08 m)	
Nozzle type	Tee Jet 1100067	Spray gun
VMD	233 μm	500 μm
Pressure	1 MPa	1.5 MPa
Spraying angle	0° (vertically down)	45° (horizontal direction)
Single width	4–5 m	8–10 m
Spray rod length	1.8 m	1.0 m
Nozzle numbers	4	1
Flow rate (one nozzle)	280 ml min^{-1}	3500 ml min^{-1}
Working height	0.5–1.5 m	0.5 m
Driving speed	3–5 m s^{-1}	0.8–1 m s^{-1}
Tank capacity	15 L	400 L
Spraying pattern	Low volume and high concentration	High volume and low concentration

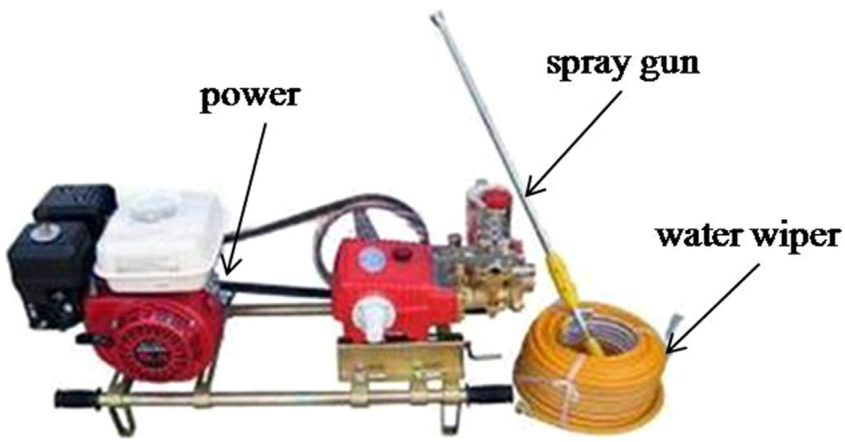

Fig. 1. The diagram of stretcher-mounted sprayer.

Table 2
Wind speed and air temperature averaged over 1 min during the measurement arrays.

Measurement height	Wind speed (m s^{-1})	Air temperature (℃)
0.8 m	1.2 ± 0.5	27.3 ± 0.6
1.5 m	1.3 ± 0.8	29.2 ± 0.5
2.0 m	1.3 ± 0.7	

The data in the table are mean ± SD.

2.4. Evaluation of droplet deposition

The experimental methods that were used to evaluate the distribution of droplets that were sprayed by the UAV in the rice canopy included the paper card method, measuring particle diameter spectra, field control effect zone setting, sampling point arrangement, operation parameters, and field environmental parameters, deposition coverage measurement and statistical methods.

2.4.1. Measuring the diameter spectra of droplets by the paper card method

A spray test was conducted on a windless day or under light air conditions (wind speed < 1.5 m s^{-1}). Water-sensitive paper (WSP, 25 mm × 75 mm) was placed in the upper part of the crop (the second leaf), where the lateral interval (n = 7) and longitudinal interval (n = 3) were 1 and 5 m, respectively, as shown in Fig. 1. The flight height and speed of the UAV were 1.2 m and 4 m s^{-1}, respectively. Under the above conditions, the deposition distribution rule of droplets with different diameters in the rice canopy was investigated *via* statistical analysis using image processing software (Sudheer and Panda, 2000; Qi et al., 2009).

2.4.2. Arrangement of the control zone

The experiment was carried out in the rice paddies of Jianxin Farm (Junshan, Hunan Province, China) in September 2014, which is the season for controlling the rice plant hopper. Rice paddies were rectangular in shape, with a size of 20 × 60 m^2.

480 g l^{-1}Chlorpyrifos·Regent EC (at dose of 432 g a.i. ha^{-1}, spray volume rate of approximately 15 L ha^{-1}) was sprayed using the HyB-15L UAV. The experiment field consisted of three zones: Zones A, B, and C. Each zone was divided into six parts, and six different treatments were performed randomly, as shown in Table 3.

2.4.3. Working parameter settings

A single-spraying swath droplet penetrating test, multiple spraying swath droplet deposition distribution uniformity test, and rice plant hopper control effect test were performed in the rice canopy. The influences of the flight height and speed of the UAV on the deposition density, coverage rate and control effect of the

Table 3
Design and division of the experimental zones.

Zone number	Treatment code					
A	x1	x3	x6	x2	x5	x4
B	x6	x4	x5	x2	x1	x3
C	x3	x5	x1	x4	x6	x2

Table 4
Testing program on deposition density, coverage rate and control effect.

Treatments	Flight height (m)	Flight velocity (m s^{-1})
x1	0.8	3
x2	0.8	5
x3	1.5	3
x4	1.5	5
x5	Stretcher spray as shown in Table 1	
x6	Control	

droplets were evaluated based on the design of two factors and two levels (Table 4).

2.4.4. Arrangement of the sampling point

In the single-spraying swath droplet penetrating test, the WSP (25 × 75 mm) was attached to the upper part (the second leaf) and the lower part (250 mm above ground) of the rice by clips, as shown in Fig. 3. The layout of WSP was consistent with that in Fig. 2.

The preset spraying zone for the multiple spray droplet deposition distribution uniformity test is presented in Fig. 4. The WSP was fixed on the upper part of the rice (the second leaf), where the lateral interval ($n = 7$) and longitudinal interval ($n = 3$) were 1 and 5 m, respectively. The total number of measured points was 21, and each collection was repeated three times.

The WSP was carefully picked down using clean tweezers and sealed in Ziploc bags for qualitative analysis, i.e., droplet coverage rate and deposition uniformity. The collected samples were analyzed in the laboratory of Nanjing Research Institute for Agricultural Mechanization, Ministry of Agriculture.

2.4.5. Coverage rate of droplet disposition

The droplet coverage and distribution uniformity are two important parameters of droplet deposition (Zhu et al., 2011). The ratio of the pixel number of the droplets covered to the analyzed zone gives the coverage of the droplets on the sample card (Cunha et al., 2012) and could be calculated by the following equation:

$$\delta = \frac{\sum_{i=0}^{M}\sum_{j=0}^{N} f(i,j)}{MN} \times 100\% \quad (1)$$

where M and N represent the pixels in the width and height of the analyzed zone, respectively. f (i, j) is the gray value of the pixel at

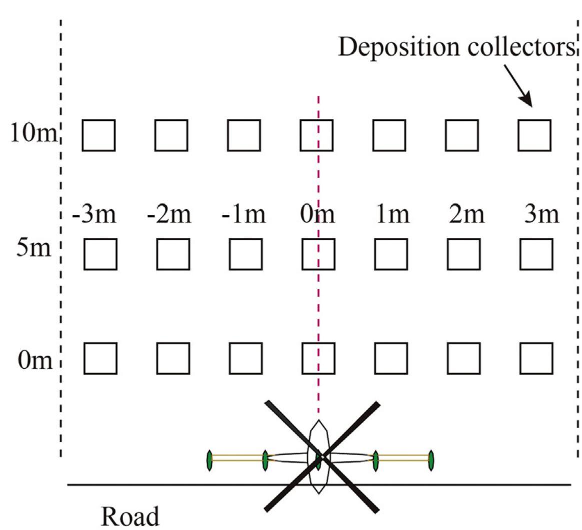

Fig. 2. Layout of the droplet sampling cards (top view).

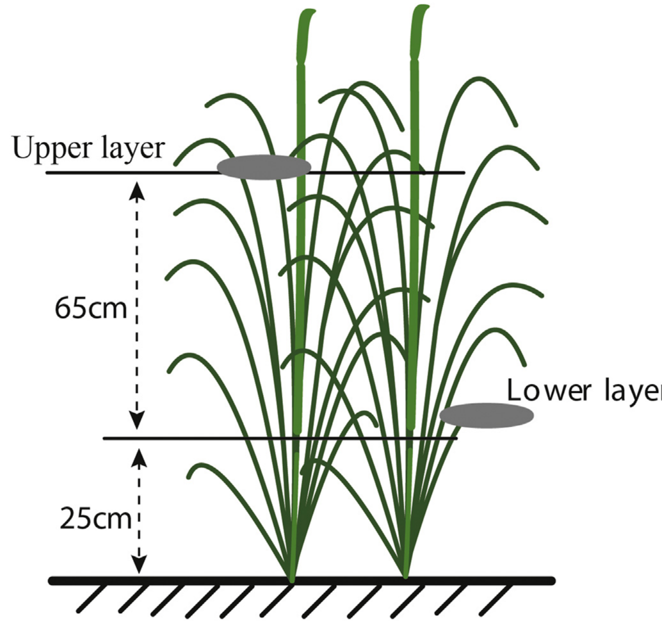

Fig. 3. Sketches of sampling collectors on the rice.

the relative coordinates of (i, j) in the analyzed zone. If the pixel is black, f (i, j) = 1; otherwise, f (i, j) = 0.

The coefficient of variation (CV) was used as a measure of the droplet distribution uniformity (Smith, 1992), according to the equation below:

$$\mathrm{CV} = \frac{S}{\overline{X}},\ \mathrm{S} = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \overline{X})^2}{n-1}} \quad (2)$$

where S is the standard deviation; X_i is the number of droplets per unit zone in the sampling card; $\overline{X}$ is the average number of droplets per unit zone in the sampling card; and n is the total number of sampling cards in each rice layer.

The survey and recordation of rice plant hopper were carried out according to pesticide field efficacy test criteria. To investigate the control effect of pesticide on rice plant hopper, the parallel-jump method was used to survey the population numbers of rice plant hoppers in each zone before spraying and 3, 5, and 10 days after spraying. During the survey, each zone was collected using 15 pieces of white porcelain (3 cm × 40 cm, 2 rice for each white porcelain, total = 30 rice). The overall control effect against rice plant hopper was calculated without regard to the types or instar of rice plant hopper. The dropping rate and control effect were obtained based on the population numbers of live insects in each zone before spraying and after spraying according to the following equation:

$$R = \frac{B - A}{B} \times 100\% \quad (3)$$

where R is the dropping rate of insects, B is the number of live insects before spraying and A is number of live insects after spraying.

$$E_1 = \frac{R_{PT} - R_{CK}}{1 - R_{CK}} \times 100\% \quad (4)$$

where E_1 is the correction control effect, R_{PT} is the dropping rate of insects in the spraying zone and R_{CK} is the dropping rate of insects in the controlled zone.

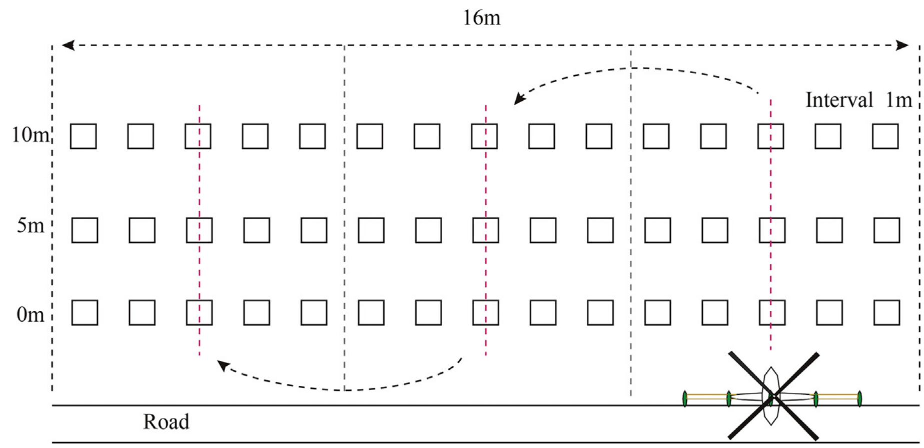

Fig. 4. Layout of droplet sampling cards in a multi swath (top view).

3. Results and discussion

3.1. Regularity of droplet size distribution in rice canopy

Grasping the regularity of droplet size distribution is of great importance to control the spray process because the droplet size is one of the most important parameters for spray technology (Knoche, 1994). Fig. 5 shows the distribution of the droplet diameter sprayed by the HyB-15L UAV. The size spectra of the droplets display a typically normal distribution curve, in which fine droplets (50–100 μm) and coarser droplets (400–450 μm) account for 13% and 10% of the total size spectra in the upper layer, respectively. The appearance of these droplets is not desirable in the pesticide spraying process. The undersize droplet size (<50 μm) can easily drift, while the oversized droplets (>400 μm) have difficulty penetrating into the canopy layer of the crop. In the lower layer, the percentage of the droplets corresponding to the size of 50–100, 100–200, and 200–300 μm was 55.5%, 33.7%, and 8.1%, respectively. In addition, droplets with a size exceeding 300 μm were only 2.8% of the total number of the droplets. Song et al. (2007) reported that the fine droplets (<50 μm) were inclined to lose their kinetic energy quickly and maintained a suspended state in air, either combined with other droplets or blown away to drift by the external wind. In contrast, coarser droplets reduced the air-borne drift loss significantly compared to fine droplet spray applications (Jaeken et al., 2003; Wenneker et al., 2005). However, coarse sprays, especially at a lower spray volume, might yield a poor spray coverage, arousing growers' fears of reducing the biological efficacy of the treatment (Smith et al., 2000). Jaeken et al. (2003) proposed a feasible way to reduce drift by changing the droplet size distribution and reducing the fraction of droplets below 100 μm. The desired size of the droplets is in a medium range between 50 and 300 μm, the relative content of which is approximately 59.2% in the upper layer and approximately 97% in the lower layer (Fig. 4). The increase in the proportion of medium droplet size not only improves penetrability but also inhibits drift (Hewitt, 2008). The use of low-drift nozzles is beneficial for drift reduction.

The change in droplet size generates diverse kinetic energy even if the nozzle velocity of droplets is the same. In addition, undersize and oversize droplet diameters both have difficulty landing on the target and forming a uniform disposition due to the interference of meteorological conditions and wind field by the helicopter rotor (Tolfo and Staudt, 1976). As seen in Fig. 5, the coarse droplets (400–450 μm), whose proportion in the total droplets is 10%, were prevailingly deposited along the central axis of the UAV and were

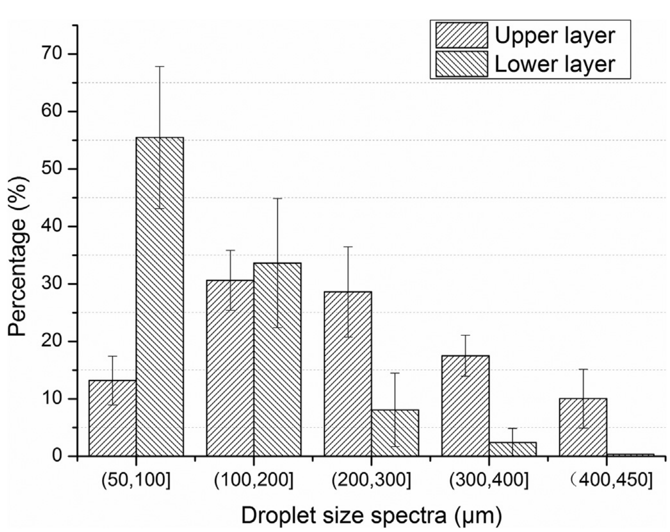

Fig. 5. Distribution of the droplet diameter in the upper and lower layers in the rice canopy.

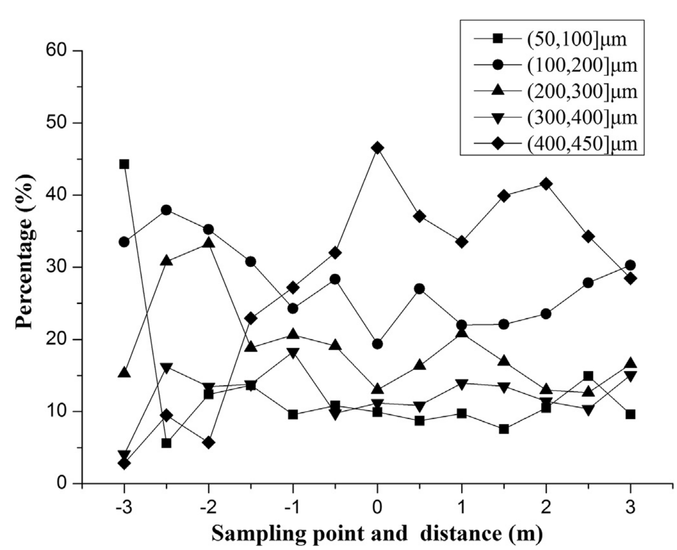

Fig. 6. Percentage of droplet size spectra at different sampling sites.

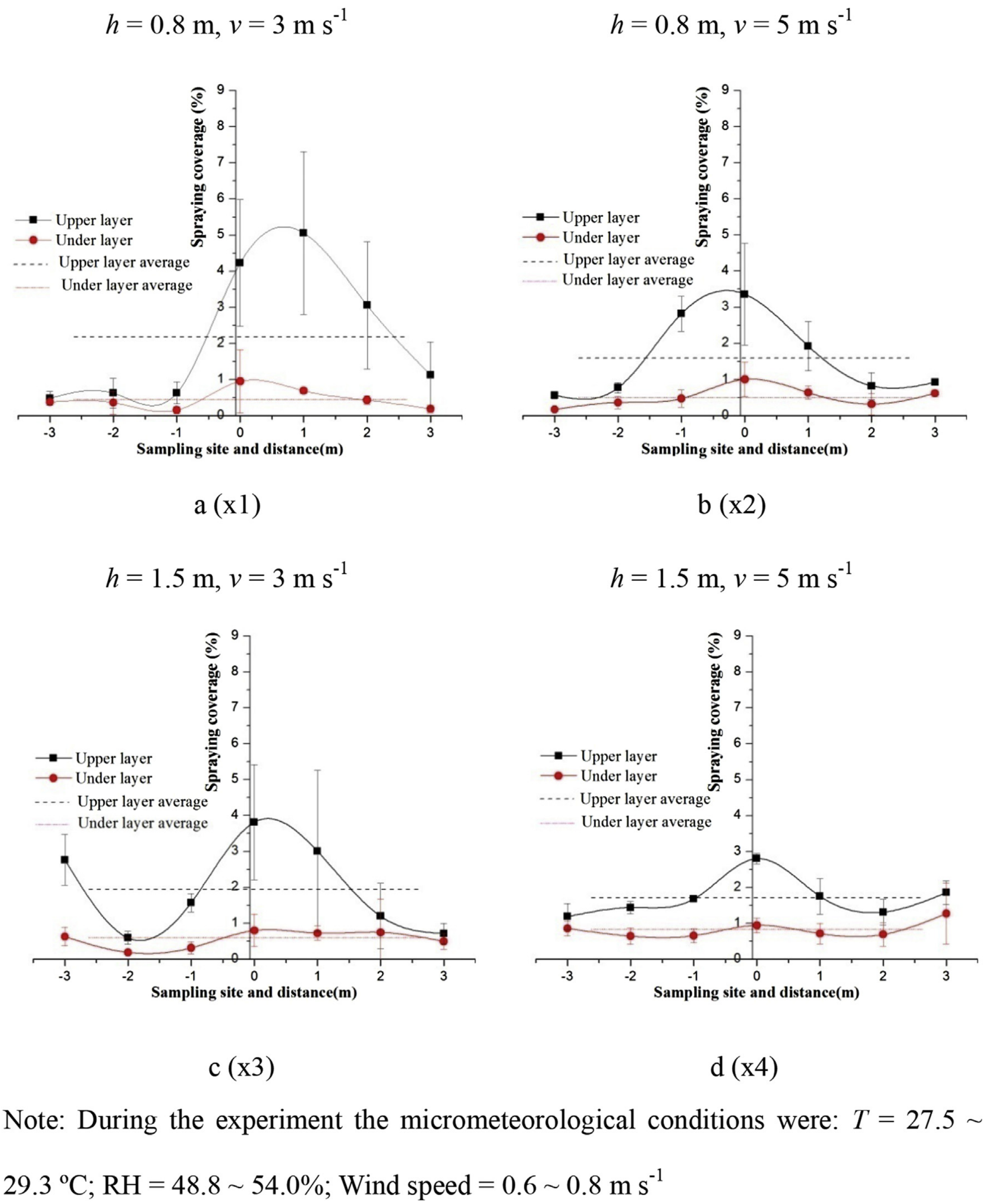

Fig. 7. Distribution diagram of spraying coverage under different working experimental conditions.

concentrated in the range of [-1, 2] m. The deposition amount of droplets was the largest in the zero site of the central line, while the deposition volume decreased with the distance from the central line, and the distribution became uneven. This result occurred because the kinetic energy of the droplets is large when they are ejected from nozzle. Moreover, the airflow under the body of the UAV caused by rotor wing is stable (Sunada et al., 2005). Therefore, coarser droplets could deposit on the surface of the rice at a relatively fast speed. Sunada et al. (2005) summarized the formation rule of the vortex at both ends of the spray lance and the annular flow at the wing tips during the spraying application from a large helicopter. The vortex caused by rotor wing at both ends of the spray lance changed the original morphology and trajectory of droplets, leading to the superior distribution of coarse droplets produced at both ends of the spray lance. As presented in Fig. 6, fine droplets (50–100] μm constituting 13% of the total droplets appeared at both ends of the spray lance. Although easy to drift, the proportion of fine droplets was not high. Medium droplets (100–300] μm constituted 59.2% of the total droplets, and mostly concentrated at two sides of the central axis, the portion of which

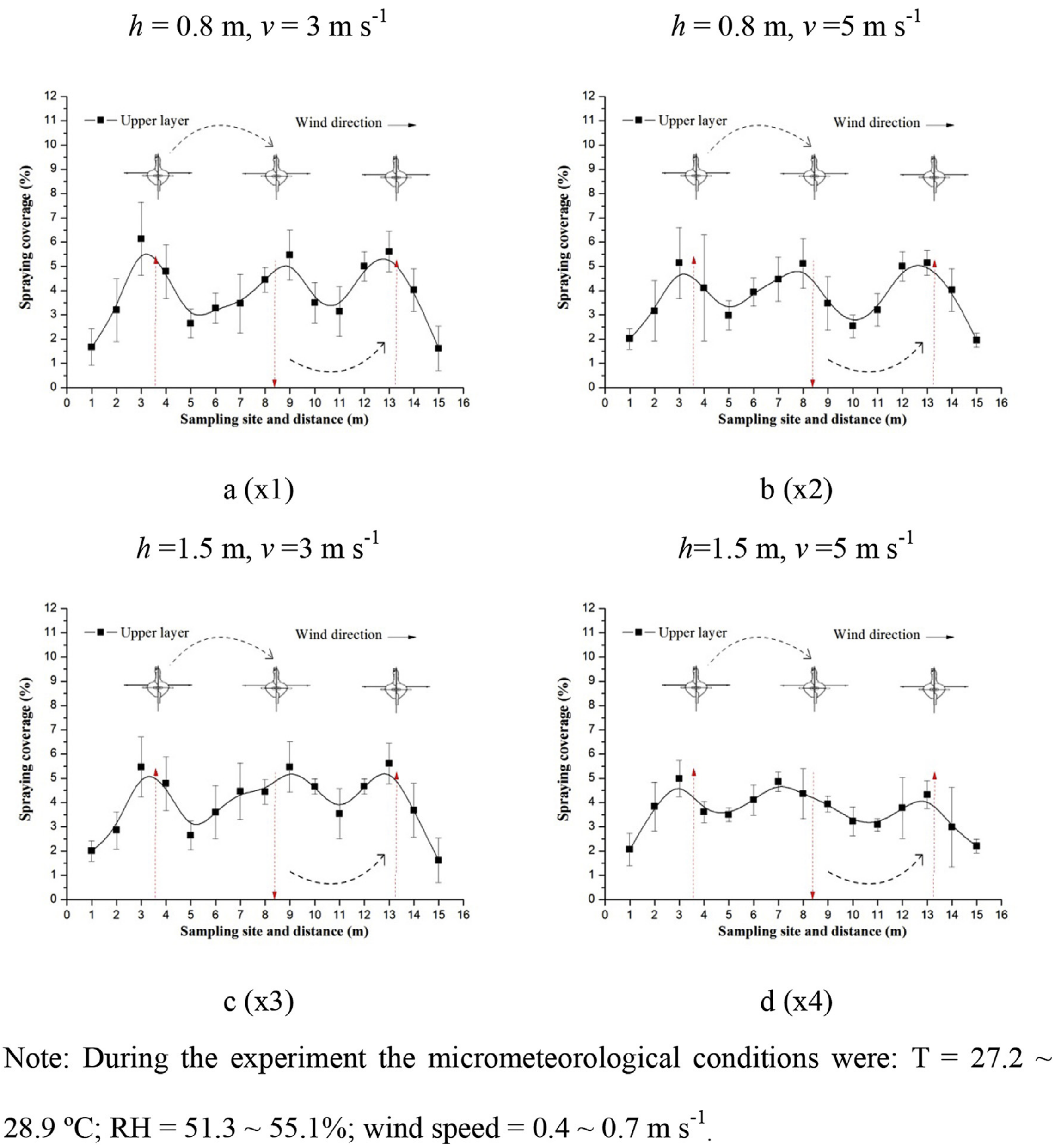

Fig. 8. Droplet distribution curves of the multi-spraying swath under different working experimental conditions.

was the lowest on the centerline and gradually increased outwards.

3.2. Analysis of deposition effect

3.2.1. Effects of spraying by UAV on droplet penetrability in the rice canopy layer

To control the drift and to improve the adhesive rate of solution, it is crucial to enhance the droplet penetrability and obtain a homogeneous deposited distribution by optimizing the working parameters of the UAV. As seen in Fig. 7a, a slow flight speed (3 m s^{-1}) makes abundant droplets deposit in the upper layer of rice. With the increased flight speed (Fig. 7b and d), the spraying coverage decreased in the upper layer of rice but increased gradually in the bottom layer. The spraying coverage in the upper layer of rice was higher under the treatment conditions of x1 and x3 than of x2 and x4. Moreover, the spraying coverage under the x1 treatment reached 2.18%, which was the highest. The average coverage rates in the upper layer of treatment x1, x2, x3, and x4 were 2.2%, 1.6%, 2.0%, and 1.7%, respectively. Due to the disturbance caused by the plant height and leaf area index, the coverage rate in the lower layer was smaller than that in the upper layer. Treatments x1, x2, x3, and x4 had average coverage rates of 0.5%, 0.5%, 0.6%, and 0.8%, respectively, in the lower layer, while the maximum value was found in treatment x4. This result is likely attributed to the fact that the downwash airstream generated by the UAV was conducive for the disturbance of leaves and that more droplets could reach the lower layer across the canopy.

Canopy structure is one of the most important factors influencing the droplet deposition and distribution (Xu et al., 2006a, 2006b; Rawn et al., 2007). Generally, crops in the upper and outside regions are likely to gain more depositions than are those inside the canopy. In addition, in many practical situations, the initial deposition is strongly related to spray technology, such as sprayer type, sprayer settings, and nozzle type. Referring

Table 5
The control efficiency of rice plant hopper at the rice heading stage.

Pesticide pattern	Insecticide	Dosage (g ha^{-1})	Treatments	Base num. (ind.)	Days after treatment (d)	Surviving insect (ind.)	Insecticidal effect (%) (mean ± SD)	Correction control efficiency (%) (mean ± SD)
HyB-15 UAV	480 g L^{-1} Chlorpyrifos ·regent EC	432	x1	88.9 ± 3.3	3	18.3 ± 1.6	78.7 ± 6.7c	81.8 ± 5.9c
					5	21.5 ± 2.0	75.8 ± 2.7b	65.5 ± 3.8b
					10	27.6 ± 2.2	69.0 ± 2.6c	62.5 ± 3.2c
			x2	87.6 ± 4.87	3	12.5 ± 2.0	86.5 ± 3.0 ab	88.5 ± 2.6 ab
					5	12.7 ± 4.24	85.6 ± 4.8a	79.4 ± 6.8a
					10	21.9 ± 3.3	74.8 ± 2.1 b	69.6 ± 5.8c
			x3	87.1 ± 3.73	3	15.3 ± 2.8	83.8 ± 3.5bc	86.2 ± 2.9bc
					5	18.2 ± 4.3	79.0 ± 5.1b	70.2 ± 7.3b
					10	24.48 ± 1.56	71.9 ± 1.6bc	66.0 ± 1.9bc
			x4	88.3 ± 5.7	3	8.5 ± 1.6	90.3 ± 1.8a	91.7 ± 1.5a
					5	11.6 ± 3.1	87.0 ± 2.7a	81.6 ± 3.9a
					10	18.8 ± 0.9	78.6 ± 2.5a	74.1 ± 3.0a
Stretcher mounted sprayer	480 g L^{-1} Chlorpyrifos ·regent EC	432	–	88.8 ± 1.4	3	12.5 ± 2.0	85.4 ± 6.6 ab	87.5 ± 5.6 ab
					5	17.2 ± 3.2	80.6 ± 3.9b	72.4 ± 5.6b
					10	26.7 ± 0.9	70.0 ± 0.8c	63.7 ± 0.9c
CK	–	–	–	89.2 ± 6.7	3	104.2 ± 6.6	0.0 ± 0.0 d	0.0 ± 0.0d
					5	62.0 ± 10.9	0.0 ± 0.0 d	0.0 ± 0.0 d

Note: Surviving insects were averaged from the leaves of 25 hills.
The data in the table are mean ± SD.
Data followed by different small letters in the same column are significantly different among different treatments at $P < 0.05$ by Duncan's new multiple range test.

specifically to aerial spraying, the penetrability and homogeneous deposited distribution of the droplets primarily rely on the flight height and flight speed in minor natural wind. The downward air flow from the rotor wing could actuate the movement of rice leaves, thus augmenting the droplet deposition in the bottom layer of rice. Because the research on UAVs is still in the initial stage, a handful of open questions need to be clarified, such as route planning (Sujit et al., 2013) and the functional law of pesticide droplets acted on by rotor downward air flow (Steven et al., 2013).

3.2.2. Effects of UAV spraying on the uniformity of droplet distribution

The uniformity of spraying droplet distribution on targets is commonly described by the variation coefficient. The smaller a variation coefficient is, the better is the uniformity of the droplet distribution (Smith, 1992). The comparison diagram of droplet deposition at different sampling sites, spraying heights and speeds is shown in Fig. 7. Before spraying, a handheld GPS locator was used to collect the coordinates of each spraying zone. The recorded data were then imported into the operation system to ensure the flight route of UAV along the preset central line. At a spraying height of 0.8 m and a speed of 3 m s^{-1}, the maximum value, minimum value, and average value of the spraying coverage were 6.1%, 1.6%, and 3.9%, respectively, with a variation coefficient of 34.5% in three spraying swaths. There was a lower spraying coverage associated with spraying swath (Fig. 8a). It is likely that, due to the low flight height, a combined interaction between horizontal wind and vertical wind generated by rotor wing resulted in the droplet break up and shifting (Wang et al., 2013). As presented in Fig. 8b, the maximum value, minimum value, and average value of the spraying coverage were 5.2%, 2.0%, and 3.8%, with a variation coefficient of 29.5% at a spraying speed of 5 m s^{-1} in three spraying swaths. The uniformity of droplet distribution improved. At a spraying height of 1.5 m and a speed of 3 m s^{-1}, the maximum value, minimum value, and average value of spraying coverage were 5.61%, 1.62%, and 3.97%, respectively, with a variation coefficient of 31.6% in three spraying swaths (Fig. 8c). The spraying problems with overlapping and missing areas were also observed at the junction of the spraying swath. When the spraying height and speed were 1.5 m and 5 m s^{-1}, the maximum value, minimum value, and average value of spraying coverage were 5.0%, 2.10%, and 3.7%, respectively, with a variation coefficient of 23.2% in three spraying swaths (Fig. 8d). Thus, when the spraying height was 1.5 m and the spraying speed was 5 m s^{-1}, the uniformity of the droplet distribution as implemented by a multi-spraying swath was optimal.

3.2.3. Effects of UAV spraying on plant hoppers control

To clarify the superiority of HyB-15L UAV spraying on rice insect control, we compared the control effect of UAV spraying with low-volume and stretcher-sprayer spraying on plant hoppers. As shown in Table 5, the control efficiency of x4 on the 3rd day after pesticide application was 91.7%, significantly outperforming that of x1 and x3. However, there was no obvious difference between the x4 treatment and the stretcher sprayer in control effects. On the 5th day, the control efficiency of x2 and x4 was 79.4% and 81.6%, respectively, notably higher than that of x1 (65.5%), x3 (70.2%), and stretcher sprayer (72.4%). As the treatment time further increased to the 10th day, x4 (74.1%) still showed a better efficiency than did x1, x2, x3, and stretcher sprayer. The control efficiency of the stretcher sprayer decreased by 23.8% from the 3rd to the 10th day. Compared to the stretcher sprayer, the control efficiency of x1, x2, x3, and x4 showed a lower reduction, decreasing by 19.3%, 18.8%, 20.2%, and 17.6%, respectively. In a brief summary, the controlling efficiency and duration period of the UAV greatly outbalanced those of a stretcher sprayer, where the UAV spraying of x4 showed the best control effect (91.7%–74.1%) from the 3rd to the 10th day. It has been reported that the duration period of high-concentration spraying was longer than that of the low-concentration counterpart (Jiang et al., 2013). The spraying manner of the UAV was low volume and high concentration. Moreover, the air stream that was generated by rotor wings could perturb the rice, and the droplets were prone to penetrating the canopy layer, reaching the bottom of the rice. Lee (2008) used mist and colored smoke as displaying carriers to determine the rules of the air stream of rotor wings on pesticide droplet action and successfully observed the wind field of the UAV and trajectory of pesticide droplets. However, the present description of downwash flow under the UAV on droplet disposition remains non-quantitative, especially for the vertical component of wind field, which needs to be further investigated.

In our current study, the spraying method of the stretcher-mounted sprayer is chosen as the high volume and low concentration, because of higher working efficiency. However, it is easy to result in larger droplet sizes and run-off onto the soil. Due to the absence of assistant airflow, the droplets were mainly deposited in the upper or middle-upper hierarchy of rice rather than the bottom, leading to prominent deterioration on the 5th day after pesticide application. Take the advantage of UAV, the operator can keep away from the pesticide field to avoid pesticide contiguity. As for the environmental concerns, more meticulous work is required to investigate the effect of chlorpyrifos at high concentrations in the long-term, which have been mapped out in our following study.

In conclusion, the farm-oriented UAV HyB-15L was first applied to control plant hoppers using low-altitude pesticide spraying during the heading stage of rice. We studied in detail the deposition distribution of droplets in the rice and the controlling efficiency correlated with the operating altitude and velocity. The conclusions from the experiments can be summarized as follows: (1) in the certain range of height (0.8–1.5 m) and velocity (3–5 m s^{-1}), the coverage rate of droplets in the bottom of the rice increased with the increased spraying height and velocity. The distribution of these droplets became more uniform when multiple spraying swaths were jointed. Meanwhile, repetitive and omitted spraying were greatly reduced. (2) The spraying height played a significant role in the uniformity of deposition distribution, and the spraying velocity strongly affected the coverage ratio of pesticide droplets, especially in the bottom of the rice. (3) For the control of plant hoppers, the UAV spraying exhibited a superior efficiency than did the conventional stretcher sprayer, especially when operated at an altitude of 1.5 m and a velocity of 5 m s^{-1}. Moreover, even 5 and 10 days after pesticide application, a high controlling efficiency was still reserved, indicating that the spraying method of low volume and high concentration enhanced the duration of pesticide activity.

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Drift and deposition of ultra-low altitude and low volume application in paddy field

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Abstract: Field trials were performed to evaluate various techniques for measuring spray deposition and aerial drift during spray application to paddy field. The application of a spraying agent containing the fluorescent dye Rhodamine-B was applied by an unmanned aerial vehicle (UAV) which flew at a height of 5 m, a speed of 3 m/s, and the wind speed of 3 m/s. The results showed that because the downdraft produced by a helicopter rotor increased the penetrability of crops, there is a higher deposition on the upper layer and the under layer than the traditional spraying. The average deposition on the upper layer accounts for 28% of the total spraying, the deposition on the under layer accounts for 26% of the total spraying. The deposition on the under layer takes up 92.8% of the deposition on the upper layer. Droplets drift data showed that the drift of non-target area took up 12.9% of the total liquid spray. The 90% drifting droplets were located within a range of 8 m of the target area; the drift quantity was almost zero at a distance of 50 m away from the treated area.

Keywords: paddy field, ultra-low altitude, low volume, UAV, droplet drift, deposition
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1 Introduction

Agricultural machinery is an important content of agricultural modernization. Since the mid-19th century, men began to widely use animal traction of simple agricultural machinery in agricultural production in Europe and the United States. In the early 20th century, men began to use the tractor of internal combustion engine power which gradually replaced livestock-power agricultural machinery. In the 1920s, the United States began to use aerial application of pesticide, which created a history of agricultural aviation[1].

Rice is the major grain crop in China. It accounts for about 42.2% of national cereal production, 35.2% of the total grain sowing area, and about 34% of insect pest control area over the years, which is one-third of the total control amount. For a long time, the rice disease prevention and control mainly relied on the human-carrying motorized sprayer which was labor-intensive, poor in quality and low in efficiency. Aerial spraying operation can control severe diseases and insect pests over a large area quickly and effectively, and it is an effective way to solve the special field operating condition of the rice fields[2,3]. However, for a long time, the application of large-scale agricultural aircraft developed slowly due to the poor economic and

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low-flying control. Compared with manned aircraft, the advantages of light unmanned aircraft are obvious: ① by the spraying at very low altitude fly, it avoids the problem of aircraft flight control; ② without special takeoff and landing at airport, it has good mobility; ③ the weight is light and cost is low. Therefore, in recent years, people have started to pay attention to using unmanned helicopters in agriculture. At the same time, according to the land management mode in China, such as the status quo that rice mainly grow in the small area of slope fields or terraces, the high adaptability of unmanned spraying aircraft has good market potential and industrial prospect.

At present, there are many reports about pesticide spray quality research conducted by researchers from China and other countries, which can provide a very useful basis for the transformation of spray components[4-7]. Aviation spraying methods have been reported both in China and in international journals, such as the method developed by Franz[8], who used the fluorescence spectrometry to quantify the deposition by analyzing the picture of plant leaves and leaves light-sensitive test paper, and determined the droplet deposition impact of the plant canopy cover characteristics and climatic parameters on cotton, cantaloupe, leafy plants in aircraft spray conditions. Ru et al.[9] studied on the air electrostatic spray and measured deposition with carbon paper and determined drift by eosin staining. Lan et al.[10] at USDA Southern Research Center collected droplet deposition in the cotton canopy, wind drift by water-sensitive paper and mylar cards in the research of fixed-wing aircraft spray. The water-sensitive paper and mylar cards was marked and collected after dried. They read and analyzed the water-sensitive paper with droplet analytical instruments, and analyzed the mylar cards with fluorescence spectrometry. It was used to calculate the deposition, droplet size, droplet coverage, total droplet number, drift distance, additive concentration, and spray height correlation. The results of the research contributed to the selection of appropriate anti-drift additives for aerial spraying, and facilitated aircraft spraying to meet the standards of aviation drift. Fritz et al.[10-13] took this method to carry out aerial spray drift and ground equipment spray drift comparison test for the research of spray drift control technology.

Based on the situation that spray distribution research of unmanned helicopter in paddy crops has not been reported, the current research did a UAV spray droplets deposition and drift law test to provide s theoretical basis and data support to the spray drift control and the development of aviation spray standards.

2 Materials and methods

2.1 Location and spray environmental conditions

This experiment was implemented in the rice fields of Xiongfeng Village, Lili County, Wujiang Town, Suzhou City, Jiangsu Province, China. It was one of the designated test areas of China's National 863 Project. The plots were planned as a rectangular land, with no buildings or trees around. Spray in the same conditions for both the control area and the treated area would not affect spray drift and deposition. The spray solution was pesticide mixed with fluorescence tracer (Rhodamine-B, Shanghai Huachen Co., Ltd.). The collector was polyester cards and polyester fibers according to ISO22866 standard. Zhou and Xue[14,15] used the electric centrifugal nozzle in the research of the UAV aerial spray optimum operating parameters, and determined the spray height, flow rate, diameters of droplet size, nozzle settings and crop characteristics that are summarized in Table 1.

Table 1 Application: sprayer settings and crop characteristics

Nozzle type	Rotary atomizer
Droplet size	296.29 μm
Working width (two nozzles)	7 m above canopy
Flow rate (one nozzle)	850 mL/min
Spray equipment	Z-3 UAV
Tank capacity	20 L
Working width	21 m in total; divided into 3sections of 7 m each
Driving speed	10.8 km h^{-1}
Spray volume	15 $L \cdot ha^{-1}$
Rh-B concentration	2 $g \cdot L^{-1}$
Crop type	rice paddies-Wugengyu 23
Plant age	Mid-tilling stage of crop growth
Soil coverage	90-100%
Crop height	0.65-0.70 m
Leaf Area Index	7.05 $m^2 \cdot m^{-2}$

We used the digital temperature and humidity indicator (Wanyitong Instrument-meter Inc., Shenzhen, Guangdong), China to record the temperature and humidity from 1.0 m and 2.0 m above the crops every 60 seconds. And we used the wind speed measuring instrument 8901 (Wanyitong Instrument-meter Inc., Shenzhen, Guangdong, China) to record the wind speed from 1.0 m, 2.0 m, and 5.0 m above the crops and the wind direction from 2.5 m above the crops every 60 seconds.

2.2 Sampling methods

Figure 1 shows how the sampling collectors and deposition and drift collectors were arranged at the spray area. The sampling collector consists of polyester card (ϕ = 90 mm) and polyester fiber (ϕ = 1 mm). The direction of aircraft was perpendicular to the wind direction. The deposition collectors were arranged along the direction of flight, and the drift collectors were arranged along the direction of wind. In order to make the pesticide spray more stable, the aircraft took off and was hovering 20 m from the spray area, and stopped spraying 10 m away. The flight height (above the crop surface) was 5 m. We measured the droplet deposition on the rice in the spray area and the droplets drift volume in the drift area. In the spray area, the rice sampling points were arranged into a matrix of 5×3 and divided into two layers (Figure 2).

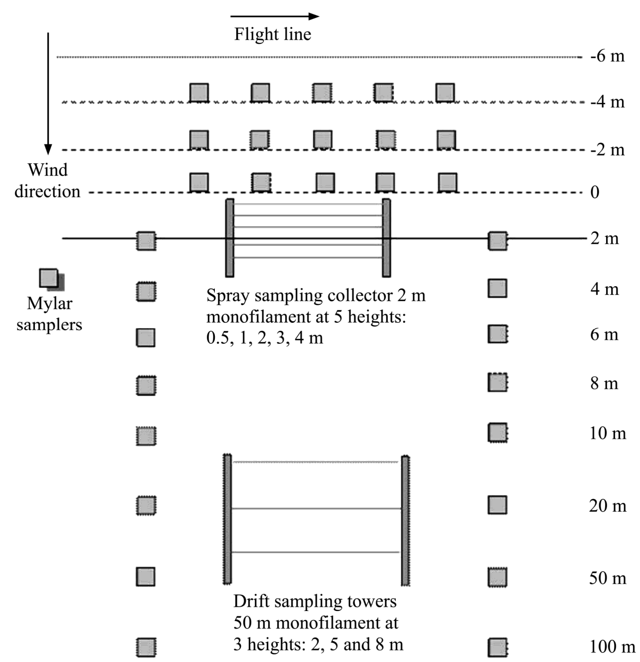

Figure 1 Layout of field sampling locations for aerial drift studies

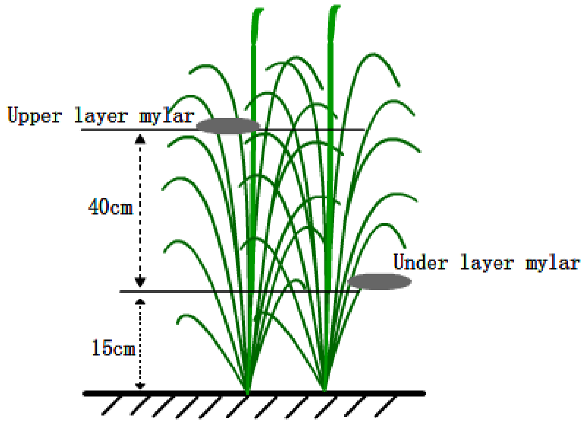

Figure 2 Sketches of sampling collectors

The interval of lateral sampling points and the interval of vertical sampling points were 2 m. In the drift area, the collector was arranged 2 m, 4 m, 6 m, 8 m, 10 m, 20 m, 50 m, and 100 m away from the spray area, in order to collect the droplet drift on the ground. We placed a trestle 2 m away from the spray area, and arranged monofilament fibers at 0.5 m, 1 m, 2 m, 3 m, and 4 m of the trestle. We placed another trestle at a distance of 50 m away from the spray area, and arranged monofilament fibers at 2 m, 5 m, and 8 m of the trestle, in order to receive the drift of the droplets in the air.

After the droplets on the collector were drying in each trestle, we wore disposable gloves to collect the polyester cards and monofilament fiber. Then we marked them, putted them in Ziploc bags, placed them in coolers, and took them back to the laboratory for analysis. We used deionized water to elute the Rhodamine-B on the film of each collector, and used the fluorescence spectrophotometer (F95) to determinate the fluorescence of each eluent. The deposition of Rhodamine-B in the eluent could be calculated according to the “concentration – fluorescence” standard curve of the Rhodamine-B standard. Liquid deposition on a unit area could be determined precisely.

The formula of deposition is

$$\beta_{dep} = \frac{(\rho_{smpl} - \rho_{blk}) \times F_{cal} \times V_{dii}}{\rho_{spray} \times A_{col}}$$

$$\beta_{dep\%} = \frac{\beta_{dep} \times 10000}{\beta_v}$$

where, β_{dep} is the spray drift deposit, expressed in microliters per square centimeter r (μL/cm^2); $\beta_{dep\%}$ is the spray drift percentage (%); β_v is the spray volume, expressed in liters per hectare (l/ha) ; β_{smpl} is the fluorimeter reading of the sample; ρ_{blk} is the fluorimeter reading of the blanks (collector + dilution water); F_{cal} is the calibration factor; V_{dii} is the volume of dilution liquid used to dilute tracer from collector, expressed in liters (l); ρ_{spray} is the spray concentration, or amount of tracer solute in the spray liquid sampled at the nozzle, expressed in grams per liter (g/l); A_{col} is the projected area of the collector for catching the spray drift, expressed in square centimeters (cm^2).

3 Results and analysis

3.1 Environment

The average air temperature and wind speed of the test is shown in Table 2.

Table 2 Wind speed and air temperature averaged over a minute during the measurement arrays

Measured quantity	Wind speed/m·s^{-1}			Air temperature/℃	
Height of measurement	1.0 m	2.0 m	5.0 m	1.0 m	2.0 m
Field conditions	2.2±0.5	3.3±0.8	4.3±0.7	28.3±0.6	29.3±0.5

Figure 3 shows that the wind speed increased with height, and the phenomenon was fitted with an exponential curve. Therefore, wind speed can be calculated from one height to another. We can take measurements on spray drift pertinently by setting different sampling heights at longer distance. Experiments were carried out at a relatively humidity of 55%±10% and a vapour pressure deficit (v.p.d.) of 37.8±6.3 mbar. In the process of spraying pesticides, the air humidity could not be too high (such as just under the rain), otherwise the droplet would fall from the leaf surface easily; and if it was too low (such as the hot noon), droplets would easily evaporate during the falling.

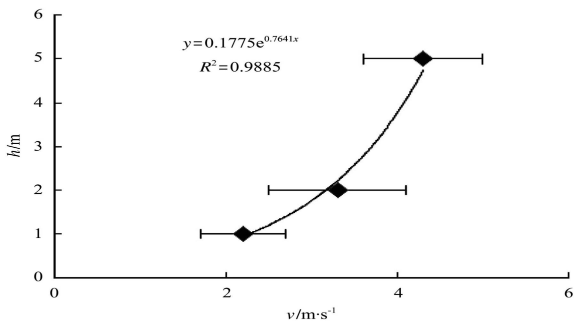

Figure 3 Curve fitting of wind speeds with height

3.2 Spray deposition between different layers of the rice plants

As we can see from the results of analysis, there was no significant difference between droplet deposition of the upper and lower rice plants in the sprayed area. In Figure 4, the dashed line indicates the average percentage of deposition in the upper and lower layers of rice plants.

Because of powerful backspin airflow, rice leaves had high deposition in the upper and lower blades. The average deposition on the upper part took about 28% of total spray volume, and the average deposition on the lower part took about 26% of total spray volume. The deposit volume on the lower part reached 92.8% of the upper part deposition.

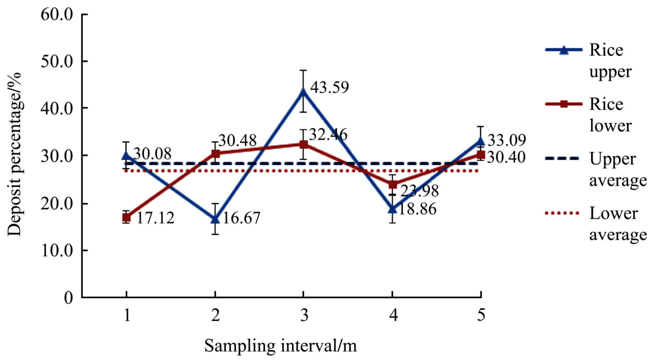

Figure 4 Rice upper and lower deposition (cm^2)

3.3 Determination of spray drift

In the test the flying height was 5 m above the crop top, and the speed was 3 m/s. The wind speed was 4-5 m/s, temperature was 34°C, and the relative humidity was 60%. The spraying area was 1 170 m^2, liquid volume was 1.8 L, and the sampling area was 1 000 cm^2.

The result of Figure 5 shows that: the droplet drift volume accounted for 12.9% of the total spray volume; while 90% of the drift was concentrated within eight meters of the sprayed area. As seen in Figure 6, on the trestle which was two meters away from the spray district, the drift of at 0.5 m height was 14.6%, and the drift of at 4 m height was 4.8%. As the altitude increased, the spray drift decreased by nearly 10%. However, on the trestle which was 50 m away, the droplet drift was almost zero.

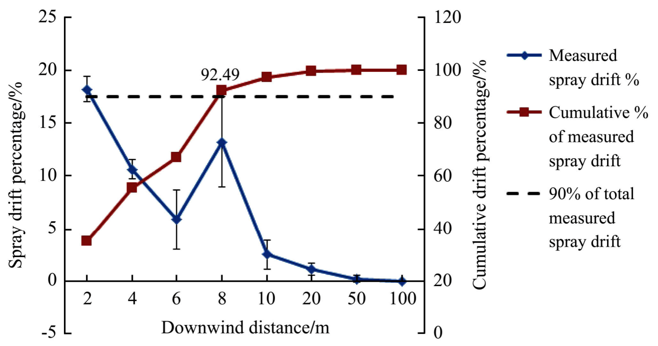

Figure 5 Drift percentage at different distances from spraying area

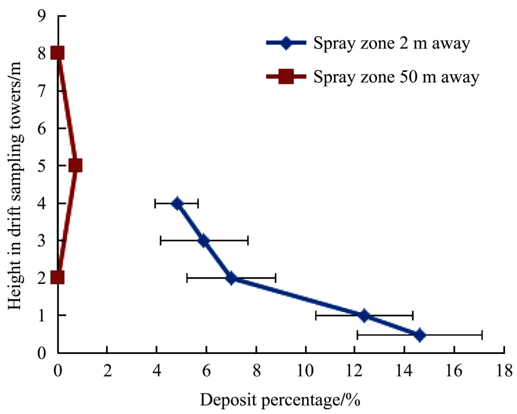

Figure 6 Drift percentage of the different heights deposition at 2 m and 50 m locations in drift area

4 Conclusions

1) We used tracer Rhodamine-B aqueous as spray liquid, and proved by the aircraft low-volume spraying test that all tests could be implemented without any auxiliaries in liquid in the operating environment where relative humidity was no less than 60% and wind speed was less than 5 m/s.

2) Because the propeller can produce a powerful downward air stream, when we use the low altitude helicopter, droplets can penetrate to the lower part of crops, and the liquid deposition of the lower part can reach 92.8% of the upper part, which has great significance in pest control.

3) In the condition that the wind speed is smaller than 5 m/s and the aerial spray height is 5 m, we can control 90% of the drift in 8 m effectively. It provides a reference for the division of buffer strip in spraying.

4) Very little research has been conducted about the basic theory of air spray technology in China up to now. The settlement laws of low-altitude spraying and the operating standards of aviation spraying safety will be the focus.

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美国农业航空技术现状和发展趋势分析*

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摘要: 美国是目前农业航空装备技术最先进、应用最广泛的国家，农业航空服务组织体系完善，航空施药作业规范，施药部件系列齐全。一些精准农业技术手段如 GPS 自动导航、施药自动控制系统、各种作业模型已步入实用阶段，作业精准、高效，对环境的污染低。随着精准农业的发展，航空遥感技术、空间统计学、变量施药控制等技术也用于美国农田产量监测，植物的水分、营养状况、病虫害监测。提出了为改善目前技术存在的不足，提高数据准确性和生产效率，需解决的主要技术问题和研究热点，包括: 图像实时处理技术、多传感器数据融合技术、航空变量喷洒技术。

关键词: 精准农业　航空施药　遥感　飘移　自动导航

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Agricultural Aviation Applications in USA

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Abstract: The United States has the most advanced equipment and applications in agricultural aviation. It also has a complete service system in agricultural aviation. This article introduced the current status of aerial applications including service, equipment, and aerial application techniques. It had a complete system including various components for aerial applications which could fit into the different applications. It had practical application of different advanced technologies such as GPS autonomous guidance, variable rate technology, and application models. This article also summarized the techniques in remote sensing, spatial statistic, and variable rate controls, and how these technologies had been used in yield estimation and monitoring for crop water and nutrient stresses, and also pest damages. This article also showed the current status of USA precision aerial application and also provided some thought of the future direction in precision aerial applications including real-time imaging processing, variable rate technologies, and multisensory data fusion.

Key words: Precision agriculture　Aerial application　Remote sensing　Drift model　GPS

引言

美国农业航空的发展已有 100 多年历史，从 1906 年，俄亥俄州使用飞机喷洒化学药剂消除牧草害虫开始，航空技术在美国农业生产中不断得到推广应用。美国农业航空作业项目主要包括: 播种、施肥、除草、灭虫等。农用飞机空中作业效率高; 突击能力强，利于消灭暴发性病虫害; 不受作物长势的限制，利于作物后期作业。与地面机械田间作业相比，使用农用飞机作业还有降低作业成本、不会损坏农

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无人直升机喷雾参数对玉米冠层雾滴沉积分布的影响

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摘 要：为了阐明喷洒药械N-3型无人直升机（N-3 UAV）在玉米生长后期雾沉积效果及应用前景，研究了喷洒参数对玉米冠层雾滴沉积分布的影响。该试验研究以染料Rhodamine-B溶解成一定浓度的溶液代替农药进行喷雾，通过改变飞机的作业高度和横向喷洒幅度进行喷雾试验；采样点设置沿玉米高度方向分4层，用聚酯卡作为雾滴取样器采集雾滴。用荧光分光光度计测定雾滴在玉米某一区域的沉积量，由此获得雾滴沉积量在玉米植株不同层间分布的规律。结果表明：作业高度为5 m时，雾滴在目标上的总沉积量最少，离散程度最大，极差值为0.17；作业高度为7 m时，雾滴在目标上的总沉积量比作业高度为5 和9 m时的沉积量大，雾滴沉积量的离散程度最小，极差为0.10；不同作业高度时，雾滴在玉米顶部、上部、穗部、下部的沉积效果和分布均匀性的变异系数不同，雾滴在玉米上部和穗部的沉积量高于顶部和下部的沉积量。在同一作业高度下（7 m），横向喷幅为5和9 m时，多喷幅雾滴沉积百分比的极差为38.4%和38.1%，变异系数为41%和34.4%；横向喷幅为7 m时，多喷幅雾滴沉积百分比的极差为26.3%，变异系数为25%，雾滴分布均匀性最好。小型无人直升机在玉米生长后期喷洒农药时，作业高度和横向喷洒幅度会影响雾滴在植株上的沉积量和分布均匀性，综合考虑雾滴沉积特性和喷洒效果情况下，应该选择飞行高度为7 m，横向喷洒幅度为7 m作为作业参数。该研究可为喷雾器具的优化设计、性能改进以及正确使用等提供技术依据；对合理喷施农药、提高喷洒效率、防治病虫害大面积暴发具有重要意义。

关键词：无人直升机；喷雾；雾滴；沉积量；分布均匀性；玉米

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Qin Weicai, Xue Xinyu, Zhou Lixin, et al. Effects of spraying parameters of unmanned aerial vehicle on droplets deposition distribution of maize canopies[J]. Transactions of the Chinese Society of Agricultural Engineering (Transactions of the CSAE), 2014, 30(5): 50－56. (in Chinese with English abstract)

0 引 言

玉米是中国主要粮食作物之一，在中国各省大面积种植，生长中后期有红蜘蛛、纹枯病、穗腐病和玉米螟（钻心虫）等病虫害发生[1-2]。在防治病虫害的过程中，施药机具是影响防治效果的一个主要因素，其质量的好坏、性能的优劣和喷施技术直接关系到农药的有效利用率以及病虫害的防治效果[3-5]。尤其是穗腐病和钻心虫，发生在玉米的穗部，因玉米叶片的阻挡效应，用常规机具喷雾，雾滴在不同部位的沉积分布呈现衰减现象，很难使药液集中到穗部以下，并且操作人员进入生长后期的玉米田喷雾作业非常困难[6]；采用地面高杆喷雾机械喷雾，需要对玉米种植方式进行改进[7]。针对高达2 m的玉米植株，玉米植保机械化是高秆作物全程机械化的瓶颈所在。目前，用于玉米等高秆作物病虫害防治的地面植保机械面临着机具难以下田进行防治和紧急应对大面积爆发性病虫害等难题[8-9]。

最为严重的是2012年8月，全国不同玉米主产区，大面积爆发粘虫危害，给玉米带来严重减产。由于自动导航无人驾驶直升机可以适应丘陵、山区和坡地等复杂地形[10-11]，能很好地用于玉米、甘蔗等高秆作物的喷雾作业，具有机动、灵活、喷雾作业效率高的特点，是防治大面积爆发病虫害的首选作业模式[12-13]。该技术的实施将改变中国传统的玉米田间施药方式，使高秆作物植保机械化的实现成为可能。目前，随着农用无人直升机的应用，针对农用无人机喷洒装置的喷雾质量和田间病虫害防治效果等一系列问题，国内外学者均进行了一些探索[14-18]。张京等[19]研究了WPH642型无人驾驶直升机喷雾参数在水稻上对雾滴沉积分布的影响。Huang等[20]开发了无人机植保作业系统，并对雾滴粒径和喷雾流量进行了研究。玉米等高秆作物的植

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Optimization and test for spraying parameters of cotton defoliant sprayer

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Abstract: Boom sprayer is widely used in large farm crops because of its high working efficiency and favorable spraying effect. But there are still some problems in cotton defoliant spraying in Xinjiang, China. Cotton is planted in a high density in Xinjiang, the row space is 10+66 cm, leaves in two adjacent rows are seriously overlapped, the lower leavers are poorly sprayed, so the defoliation effect is poor, and the cotton quality is degraded. To solve this problem and improve the defoliant droplets coverage on the cotton canopy, the original boom spraying was modified, and the spraying pardameters was optimized by the central combination test and design concept of Box-Behnken based on a single-factor test. A quadratic polynomial model of droplets coverage was created by using working parameters including horizontal spraying boom height, hang boom height and nozzles angle as the influential factors and the mean droplets coverage on cotton canopy as the target function, and the effectiveness of mode and interaction of factors were analyzed. The model was optimized and analyzed using the regression analysis method and response surface analysis method of software Design-Expert 7.0.0, and the optimal combination of spraying parameters was obtained. The results showed that the droplets coverage on cotton canopy were influenced by boom height, sprayer height and angled nozzles sequentially from large to small, and the optimal combination of spraying parameters was under horizontal spraying boom height of 134 cm, hang spraying boom height of 27.5 cm and nozzles angle of 21°. The mean droplets coverage of experimental value and predicted value on cotton canopy were 19.6% and 20.43% respectively in such conditions, and the relative error to the estimated value on the model was –4.25%. The research result can provide a reference for further optimizing the spraying parameters of cotton defoliant sprayer.

Keywords: pesticide sprayer, cotton, spraying parameter, optimization, mathematical model, response surface

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1 Introduction

Defoliant spraying is a key link in the mechanized cotton harvest, as sufficient and uniform spraying can improve the defoliation quality and decrease the cotton trash content, and it is significant to solve defects of the cotton quality[1]. But in practice, the anticipated effect are hardly to realize as the defoliant is influenced by weather and the spraying way[2]. Xinjiang is the major cotton producing area in China, where cotton is planted in a high density and cotton leaves are overlapped densely, and it was found in the production and test that the general low defoliation rate and high trash content are caused by the reason that lower leaves cannot be defoliated timely[3]. The key to improve the defoliation effect is to manually improve the droplets coverage on leaves in the middle and lower layers, and spraying the defoliant sufficiently and uniformly on the leaves. Distribution of droplets is influenced by many factors

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N-3 型农用无人直升机航空施药飘移模拟与试验

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摘 要：为了判定 N-3 型农用无人直升机在进行病虫害防治作业时所需的安全农药飘移缓冲区，该文通过模拟和试验，研究了飞机在飞行速度为 3 m/s、侧风风速分别为 1、2 和 3 m/s、飞行高度为 5、6 和 7 m 时在非靶标区域的药液飘移情况。采用计算流体力学（computational fluid dynamics，CFD）方法，在约束条件下对作业过程中旋翼风场和农药喷洒的两相流进行了模拟，并设计了条件相似的对应试验进行验证。模拟的结果表明，在无人机飞行速度 3 m/s，侧风风速相同的情况下，作业飞行高度为 5、6、7 m 时，药液在侧风下方（Z 轴正向）的最大飘移距离和在无人直升机后方（X 轴负向）的最大沉积量位置差异不大；在作业飞行高度相同的情况下，侧风风速为 1、2、3 m/s 时候，药液在侧风下方的最大飘移距离和在无人直升机后方的最大沉积量位置发生变化明显。通过相应试验，对飘移量（飞行高度 6 m，飞行速度 3 m/s）的模拟数值与试验值的变化趋势进行了比较，并进行线性回归分析，拟合直线决定系数 R^2 分别为 0.7482、0.8050 和 0.6875。本文提出一种较传统检测方法更为方便的 CFD 模拟方法，来对 N-3 型无人直升机施药作业中药液的飘移情况进行分析，模拟研究可以比较准确地定性地模拟出实际飘移情况，对实际生产具有一定的指导意义。

关键词：农药；数值分析；试验；无人直升机；航空施药；飘移

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张宋超，薛新宇，秦维彩，等. N-3 型农用无人直升机航空施药飘移模拟与试验[J]. 农业工程学报，2015，31(3)：87－93.

Zhang Songchao, Xue Xinyu, Qin Weicai, et al. Simulation and experimental verification of aerial spraying drift on N-3 unmanned spraying helicopter[J]. Transactions of the Chinese Society of Agricultural Engineering (Transactions of the CSAE), 2015, 31(3): 87－93. (in Chinese with English abstract)

0 引 言

航空植保能快速高效地完成病虫草害的防治，特别是能及时有效地防治爆发性有害生物灾害，同时它不受地理因素的制约，一般不受作物生长期的影响，都可以顺利高效的完成作业任务[1-2]。小型无人直升机灵活性好，无需专用起降场地，在旋翼风场的协助作用下，无人施药直升机低空施药作业，具有作业效率高，防治效果好，提高农药有效利用率，大大降低农药中毒等优点[3]，但是由于空中作业条件与气流的影响，相对于地面机具航空作业更易产生农药飘移[4-7]。农业航空最为发达的美国，对航空喷洒作业中雾滴飘移引起的环境污染问题十分重视，对于航空施药的安全区域，已有明确的法律条文规定，飘移模型已成为决策是否允许航空施药和处理相关纠纷的重要手段[8-9]。早在 20 世纪 70 年代末到 80 年代初，美国林业局就开始用计算机模型来分析和预测航空施药中雾滴飘移情况，最早的模型是 FSCBG（forest service cramer barry grim），该模型研究天气因素、蒸发情况和冠层穿透对沉积分别的影响，预测雾滴分布，用于制定喷洒作业方案和对环境的风险评估。在 Teske 等的努力下，FSCBG 模型发展成了著名的 AGDISP（agricultural dispersion）模型，该模型将飞机尾流、翼尖涡流、直升机旋翼下旋气流和机身周边空气扰动纳入到对雾滴的影响因素，将航空施药的喷洒雾滴作为离散对象进行分析，以平均直径和体积分数为衡量参数，再将数据经过拉格朗日方程处理，得到雾滴的运动轨迹，以此来预测雾滴的运动和地面沉积模式。随着研究的不断深入，AGDISP 模型也在不断的被扩充和完善[10]。澳大利亚 Hewitt 等将地理信息系统引入到航空飘移模型中，通过对实时风速的测定来优化喷施策略，以减少在非靶标区域的农药飘移损失[10-11]；另外，在飘移方面的研究，新西兰 Praat 等开展了从喷雾器（机）和作物冠层特性角度出发，进行了一系列飘移研究；德国 Kaul 等也基于具体作物进行了相关的飘移研究，取得了一定的进展[12]。目前，国内一些学者已经开始了飘移的相关研究：薛新宇等研究了无人直升机施药装备超低空低量喷洒，在水稻病虫害防治时的药液飘移情况，结果表明当外界侧风风速小于 5 m/s、飞机喷洒高度为 5 m 时，能够有效地把 90%的飘移量控制在 8 m 内[13]；曾爱军等采用飘移潜在指数（drift potential index，DIX）作为衡量评价指标，对小喷量标准扇形雾喷头在风洞条件下进行了雾滴飘移沉积特性试验[14]；

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无人机高浓度施药对水稻品质的影响*

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3. 美国农业部南方平原研究中心，德克萨斯 77845)

摘要： 探索了 2 种常规药剂在低量高浓度无人机施药作业方式下对水稻品质的影响。采用 2 种药剂(毒死蜱 chlorpyrifos，己唑醇 hexaconazole)，2 种作业方式处理南粳 5050 一个生长季的水稻，对比采后稻谷加工品质。由航空高浓度低量喷洒与常规喷洒处理的水稻籽粒的 DMA 动力学频谱得知：飞机喷洒毒死蜱处理的水稻硬度高于常规喷洒；飞机喷洒己唑醇处理的水稻与常规喷洒作业的黏弹性指标差异不大。采用 X 射线衍射仪测定水稻籽粒中淀粉的晶体结构，结果表明：航空施药和常规施药方式对水稻籽粒的微观结构均会产生影响，航空施药对水稻籽粒的微观结构影响小于常规施药对水稻籽粒微观结构的影响。

关键词： 水稻品质 农业航空 施药 热动态力学分析 X 射线衍射

中图分类号： S49 **文献标识码：** A **文章编号：** 1000-1298(2013)12-0094-05

Effects of Pesticides Aerial Applications on Rice Quality

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2. *Nanjing Research Institute for Agricultural Mechanization*, *Ministry of Agriculture*, *Nanjing* 210014, *China*
3. *Southern Plains Agricultural Research Center*, *United States Department of Agriculture-Agricultural Research Service*, *Texas* 77845, *USA*)

Abstract: The effects of two types of commercial pesticides on the rice quality were investigated under the low volume aerial application. It could provide guidance for the pesticide application and choose the right types of pesticides. For chlorpyrifos and hexaconazole pesticides, aerial and traditional spraying on Nangeng 5050 rice was used during the growing season. The differences of postharvest rice quality and also the kernel spectrum of DMA between aerial application in high concentration and low volume and traditional spraying were investigated. It was found that rice kernel hardness for aerial application with chlorpyrifos was higher than tradition spraying application but no significant difference with hexaconazole application. With X-ray diffraction analyzer, it was found that the effect of aerial application was smaller than traditional one for the microstructure of rice kernels.

Key words: Rice quality Agricultural aviation Application Dynamic mechanical analysis X-ray diffraction analyzer

引言

使用农药进行病虫害防治是保证水稻丰产丰收的重要措施之一[1]。农药对水稻的光合作用、游离氨基酸含量、蔗糖含量、SOD 活性、根系活性等均会产生影响[2]，进而对水稻品质产生影响[3~5]。采用常规地面药械施药，农药用水稀释后通过喷雾方式分散至作物表面，通常水稻施药量为 375 ~ 750 L/hm^2。

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N-3型无人直升机施药方式对稻飞虱和稻纵卷叶螟防治效果的影响

薛新宇 秦维彩 孙 竹 张宋超 周立新 吴 萍

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摘要: 为了阐明喷洒药械N-3型无人直升机(N-3 UAV)对稻飞虱和稻纵卷叶螟的防治效果及应用前景,进行了飞机不同作业高度和不同喷洒浓度的田间药效试验。结果表明,在水稻分蘖后期,飞机每公顷喷洒48%毒死蜱·锐劲特EC 432 g(有效成分,下同),施药后3、5、10 d对稻飞虱的防治效果为96.93%、92.21%、88.12%,对稻纵卷叶螟的保叶效果为63.29%、54.00%、58.33%,均优于传统担架式喷雾机喷洒防治效果。在水稻孕穗期,无人机在3 m和5 m的作业高度下,每公顷喷洒25%吡蚜酮SC 75 g,施药后10 d对稻飞虱的防治效果与每公顷喷洒60 g和52.5 g时防治效果无显著差异;每公顷施用40%二嗪·辛硫磷EC 480 g和384 g防治稻纵卷叶螟,施药后10 d,3 m作业高度下的杀虫效果均达90.90%,优于5 m和7 m的杀虫效果。

关键词: 无人直升机; 水稻; 稻飞虱; 稻纵卷叶螟; 防治效果

Effects of N-3 UAV spraying methods on the efficiency of insecticides against planthoppers and *Cnaphalocrocis medinalis*

Xue Xinyu Qin Weicai Sun Zhu Zhang Songchao Zhou Lixin Wu Ping

(Nanjing Research Institute for Agricultural Mechanization, Ministry of Agriculture, Nanjing 210014, Jiangsu Province, China)

Abstract: The efficacy and applications of N-3 unmanned aerial vehicle (UAV) were determined against rice pests in paddy field tests at different flight heights and different spraying concentrations. The result of field test showed that under a dosage of 432 g/hm^2(ai) of 48% chlorpyrifos · regent EC at late rice tillering, the efficacy of 3, 5 and 10 days after treatment with N-3 UAV spraying was as high as 96.93%, 92.21% and 88.12%, respectively in terms of rice planthoppers. On *Cnaphalocrocis medinalis* Guenée, 63.29%, 54.00% and 58.33% rice leaves could be kept healthy, those are both superior to the efficacy of spraying with stretcher mounted sprayer. The N-3 UAV worked at the height of 3 and 5 meters under a dosage of 75 g/hm^2 of 25% pymetrozine SC at the rice heading stage, the efficacy of 10 days after treatment has no significantly different with a dosage of 60 g/hm^2 and 52.5 g/hm^2 of 25% pymetrozine SC. On *C. medinalis*, the efficacy of 10 days after treatment with N-3 UAV spraying at the 3 meters height was as high as 90.90% under a dosage of 480 g/hm^2 or 384 g/hm^2 of 40% diazinon · phoxim EC. It is better than the efficacy of the N-3 UAV working flight at 5 meters or 7 meters height.

Key words: unmanned aerial vehicle (UAV); rice; planthopper; *Cnaphalocrocis medinalis*; efficiency

基金项目: 公益性行业(农业)科研专项(201203025)

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收稿日期: 2012-12-11

农用无人机100问

◎ 薛新宇　兰玉彬　秦京光　主编

中国农业科学技术出版社

2. 重要科技奖励

中华农业科技奖
证书

为表彰在我国农业科学技术进步工作中做出突出贡献的获奖者，特颁发此证书，以资鼓励。

项目名称：高效减量精准施药技术与机具研发应用

奖励等级：一等奖

获奖者单位：农业部南京农业机械化研究所

获 奖 者：薛新宇（第4完成人）

证书编号：KJ2013-R1-007-04

中华人民共和国农业部

中华农业科技奖奖励委员会

二〇一三年十一月八日

3. 重要社会奖励

国科奖社证字第0191号

中国产学研合作创新奖

获奖证书

薛新宇 同志

为表彰在政产学研协同创新中做出突出贡献的单位和个人，在科技部和国家科技奖励办支持下，设立了中国产学研合作创新与促进奖。经评审，授予你2017年中国产学研合作创新奖。

特颁此证。

证书号：20173115

中国产学研合作促进会

2017年11月

4. 重要国际、学术机构或国际顶级学术期刊兼职情况

CIGR

Working Groups

CIGR Working Groups are appointed by the Executive Board to carry out studies on specific subjects of international importance and interest.

The Working Groups Co-ordinator assists the Chairpersons of the Working Groups in the fulfilment of their task and in providing a liaison with the governing bodies of CIGR.

Precision Aerial Application Working Group

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Missions

The mission of the Precision Aerial Application Working Group is to develop and implement new and improved precision aerial application equipment for safe, efficient, and sustainable crop production and protection.

Objectives

The overall objective of this group is to provide precision aerial application solutions for aerial applicators using cutting edge technologies. The first variable-rate aerial application system was developed about a decade ago in the USA and since then, precision aerial application has benefitted from these technologies. Many areas around the world rely on readily available agricultural airplanes or helicopters for pest management, and variable-rate aerial application provides a way of making effective and precise application of agrochemicals. In the context of precision aerial application, variable-rate control can simply mean terminating spray over field

中国农业工程学会农业航空分会第一届工作委员会名单

文章来源：中国农业工程学会农业航空分会 发布日期：2015-02-06 浏览次数：2

主任委员

梁 建

常务副主任委员

兰玉彬

副主任委员

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薛新宇

副秘书长

何雄奎 邱白晶

< 关闭 >

中国农业机械工业协会
植保与清洗机械分会文件

中农协植字〔2016〕1 号

关于植保与清洗机械分会第七届理事会组成的通知

各会员单位:

根据农机协字〔2016〕2 号文，中国农业机械工业协会对我分会第七届理事会选举结果批复，分会第七届理事会组成如下:

一、分会第七届理事会组成

第七届理事会由山东永佳动力股份有限公司等 63 家会员单位组成。

山东永佳动力股份有限公司为会长单位，陈煜林任会长。

农业部南京农业机械化研究所为常务副会长单位，梁建任常务副会长。

山东华盛中天机械集团股份有限公司等 17 家单位为副会长单位，陈秀明等 17 人任副会长。

邯郸中机美诺药械有限公司等 45 家单位为理事单位，闫洪琪等 45 人任理事。

聘任薛新宇为秘书长，吴萍、龚艳、刘春歌、张朝元等 4 人为副秘书长。

二、分会第七届理事会任期为 4 年，自 2015 年 12 月 9 日起计算。

附件：植保与清洗机械分会第七届理事会组成名单

二〇一六年一月十三日

中国农业机械工业协会植保与清洗机械分会

证书

薛新宇同志：

经第一届委员代表大会选举，您当选为中国农业机械学会农业航空分会第一届委员会副主任委员（2016—2020年）。

特颁此证。

中国农业机械学会

2016年8月

证组字第009号

国家航空植保科技创新联盟文件

国家航空植保科技创新联盟 [2016] 3 号

任命李继宇等为国家航空植保科技创新联盟副秘书长

根据国家航空植保科技创新联盟发展需要，经联盟委员会决定现任命李继宇（华南农业大学副教授）、宋坚利（中国农业大学副教授）、闫晓静（中国农业科学院植物保护研究所副研究员）和秦维彩（农业部南京农机化研究所助理研究员）为联盟副秘书长，负责联盟各项事宜的日常管理工作。

此任命自发布之日起生效。

国家航空植保科技创新联盟 委员会

2016 年 8 月 8 日

5. 主持项目（课题）情况

项目编号：2017YFD0701000　　　　　　　　　　　　　　密　级：公开

国家重点研发计划
项目任务书

项目名称：农用航空作业关键技术研究与装备研发

所属专项：智能农机装备

指南方向：农用航空作业关键技术研究与装备研发

推荐单位：农业部

专业机构：中国农村技术开发中心

项目牵头承担单位：农业部南京农业机械化研究所（公章）

项目负责人：薛新宇

执行期限：2017 年 07 月 至 2020 年 12 月

中华人民共和国科学技术部

2017 年 07 月 14 日

0002YF 2017YFD0701000 2017-07-14 11:22:54

任务书签署

甲乙双方根据《国务院关于改进加强中央财政科研项目和资金管理的若干意见》（国发[2014]11号）、《国务院印发关于深化中央财政科技计划（专项、基金）管理改革方案的通知》（国发[2014]64号）、《中央办公厅国务院办公厅印发<关于进一步完善中央财政科研项目资金管理等政策的若干意见>的通知》（中办发[2016]50号）、《科技部财政部关于改革过渡期国家重点研发计划组织管理有关问题的通知》（国科发资[2015]423号）、《科技部财政部关于印发<中央财政科技计划（专项、基金等）监督工作暂行规定>的通知》（国科发政[2015]471号）、《财政部科技部关于印发<国家重点研发计划资金管理办法>的通知》（财科教[2016]113号）等有关文件规定，以及有关法律、政策和管理要求，依据项目立项通知，签署本任务书。

专业机构（甲方）：

法定代表人签字（签章）：

（公章）

贾敬敦

2017年 8月 1日

项目牵头承担单位（乙方）：

法定代表人签字（签章）：

（公章）

陈巧敏

2017年 7月 21日

项目负责人签字（签章）：薛新宇

2017年 7月21日

推荐单位（盖章）

2017年 7月24日

农业公益性行业科研专项

项目编号： 201203025

公益性行业（农业）科研专项经费
项目任务书（2013 年）

项目名称：植保机械关键技术优化提升与集成示范

委托部门（甲方）：

农业部科技教育司

承担部门（乙方）：

主持单位： 农业部南京农业机械化研究所

首席专家： 薛新宇

中华人民共和国农业部制

二零一二年十二月

十一、合同签约各方

甲方（委托方）：

农业部科技教育司（公章）　　负责人（签章）　　2012 年12月31日

联系人:　　　　　　　　　　联系电话:

乙方（承担方）：

主持单位（公章）　　　　负责人：（签章）　　2012 年12月20日

主持单位财务部门（公章）　　负责人：（签章）　　2012年12月20日

首席专家：（签字）薛新宇　　　　　　　　2012 年12月20日

科技部成果转化项目

受理编号：201132609002
合同编号：2011GB23260031

农业科技成果转化资金项目
合同书

项目名称：新型系列均匀施药技术装备中试与示范
承担单位：农业部南京农业机械化研究所
联 系 人：薛新宇
联系电话：固定电话：025-84346243 手机：13913959328
电子邮箱：814792877@qq.com
单位地址：江苏省南京市玄武区中山门外柳营100号
邮政编码：210014
起止年限：2011年4月 至 2013年4月

中华人民共和国科学技术部
二〇一一年制

八、合同签约各方：

甲方（科技部主管单位）：中国农村技术开发中心 负责人（签字）：贾敬敦 贾敬敦 联系人：谭华 日期：2011-08-10
乙方（承担单位）：农业部南京农业机械化研究所 负责人（签字）：易中懿（签章） 联系人：许新宇 日期：2011-07-29 收款单位：农业部南京农业机械化研究所 开户银行：中国工商银行股份公司江苏省分行营业部孝陵卫支行 账　　号：4301010609001074647
丙方（推荐单位）：农业部 主管领导（签字）：杨雄年 联系人：纪绍勤 日期：2011-07-28

农业部财政项目

农业行业标准制定和修订（农产品质量安全）项目申报书

项目任务：农用遥控飞行器安全技术要求

项目类型：制定

项目单位：农业部南京农业机械化研究所

首席专家姓名：薛新宇

通讯地址：江苏省南京市玄武区柳营100号

邮政编码：210014

联系电话：025-84346243

手　　机：13913959328

传　　真：025-84346243

电子邮件：Xuexinyu2012@gmail.com

法人代表姓名：曹曙明

编 制 日 期：2013年9月18日

主管部门（单位）：中国农业科学院

280

中华人民共和国农业部制

六、申报意见表

项目单位意见	本单位对以上内容的真实性和准确性负责，特申请立项。 法人代表签名：曾曙明　　单位公章 2013年9月22日
主管部门（单位）意见	经审核，同意报送。 负责人签名：李新海印　　单位公章 2013年9月23日
农业部农产品质量安全监管局意见	280　项目名称为：制定《农用遥控飞行器安全技术要求》标准　　项目经费：　7万 本项目应于2014年12月31日前完成 单位公章 年　月　日

附件 62—2

NJH-17-4

农业行业标准制定和修订
（农产品质量安全）项目申报书

148-1

项目任务：遥控飞行喷雾机试验方法

项目类型：制定

项目单位：农业部南京农业机械化研究所

首席专家姓名：薛新宇

通讯地址：江苏省南京市玄武区柳营100号

邮政编码：210014

联系电话：025-84346243

手　　机：13913959328

传　　真：025-84346243

电子邮件：Xuexinyu2012@gmail.com

法人代表姓名：陈巧敏

编 制 日 期：2014年10月8日

主管部门（单位）：中国农业科学院

中华人民共和国农业部制

六、申报意见表

项目单位意　　见	本单位对以上内容的真实性和准确性负责，特申请立项。 陈巧敏 法人代表签名：　　　　单位公章 2014年10月24日
主管部门（单位）意　见	经审核，同意报送。 负责人签名：荣梅印 单位公章 2014年10月30日
农业部农产品质量安全监管局意见	1.制定《遥控飞行喷雾机试验方法》标准 经费8万元 该项目应于2015年12月31日完成 单位公章 年2015-09-01

七、项目单位账号

项目单位财务专用章：

项目单位账　　户	收款单位：农业部南京农业机械化研究所
	户　　名：农业部南京农业机械化研究所
	开户银行：中国农业银行股份有限公司江苏南京紫金山支行
	账　　号：10-110301040002346

江苏省自然基金项目

江 苏 省 科 技 项 目 合 同

计 划 类 别 基础研究计划（自然科学基金）--面上研究项目

项 目 编 号 BK20151074

项 目 名 称 旋翼无人机施药雾滴运动行为特性研究

项 目 类 别

起 止 年 限 2015 年 7 月 至 2018 年 6 月

项目负责人 薛新宇 电话及手机 13913959328 025-84346243

电话及手机

承担单位 农业部南京农业机械化研究所

单位地址 南京市中山门外柳营 100 号 邮政编码 210014

项目主管部门 南京市科学技术委员会

江 苏 省 科 学 技 术 厅

二〇一五年

八、签订合同各方

甲方：

法定代表人或委托代理人（签字）

项目主管处室负责人（签字）

项目主管处室经办人（签字）

公章

年 月 日

乙方：

承担单位法定代表人或委托代理人（签字）

项目负责人（签字） 薛新宇

公章

年 月 日

开户银行、帐号

中国工商银行孝陵卫分理处

帐号：4301010609001074647

丙方：

法定代表人或委托代理人（签字）

陶涛 代

公章

2015 年 9 月 11 日

江苏省现代农业装备与协同创新项目

江苏省现代农业装备与技术协同创新中心研发任务合同

项目类别 ☐ 重大产品开发☐共性技术研究

项目编号 NZXT01201403

项目名称 低空低量航空植保关键技术及装备研发

起止年限 2014 年 10 月至 2015 年 12 月

项目首席科学家 薛新宇

电话及手机 02584346243 15366092998

承担单位 农业部南京农业机械化研究所

单位地址 南京市玄武区中山门外柳营100号

邮政编码 210014

项目主管部门 江苏省现代农业装备与技术协同创新中心

江苏省现代农业装备与技术协同创新中心

二〇一四年

八、签订合同各方

甲方：江苏省现代农业装备与技术协同创新中心

法定代表人或委托代理人（签字） 毛罕平

公 章

2015 年 1 月 6 日

乙方：　农业部南京农业机械化研究所

承担单位法定代表人或委托代理人（签字）

项目负责人（签字） 薛新宇

公 章

开户银行、帐号　　　　2015 年 1 月 5 日

丙方一：　江苏大学

法定代表人或委托代理人（签字） 邱白晶

公 章

2015 年 1 月 6 日

丙方二：华南农业大学

法定代表人或委托代理人（签字）

公 章

2014 年 12 月 31 日

农业国际交流与合作项目

农业国际交流与合作项目申报书

项目任务：中美航空安全施药技术合作研究

项目单位：农业部南京农业机械化研究所

通讯地址：江苏省南京市玄武区柳营 100 号

邮政编码：210014

联系电话：025-84346234

联 系 人：张宋超

E - mail：zhangsongchao@caas.cn

主管部门（单位）：中国农业科学院

通讯地址：北京市海淀区中关村南大街 12 号

邮政编码：100081

联系电话：010-82109477

联 系 人：张立滨

填制日期：2013 年 9 月 18 日

江苏省农业科技自主创新资金项目

江苏省农业科技自主创新资金
项目合同书

项目类别：现代农业技术创新

项目编号：CX(11)2026

项目名称：果园高效植保关键技术研究与装备创制

起止时间：2011 年 06 月 至 2013 年 05 月

承担单位：农业部南京农业机械化研究所

项目负责人：薛新宇

联系电话：025-84346243 13913959328

电子邮箱：735178312@qq.com

共同负责人：

江 苏 省 财 政 厅

江苏省农业科学院

二 〇 一 一 年 制

6. 专利情况

证书号第1510367号

北京市海淀区地方税务局 印花税代扣专用章 国家知识产权局

发明专利证书

发明名称：基于模型的直升机航空施药飘移预测方法

发明人：薛新宇；张宋超；孙竹；常春；梁建；秦维彩；周立新；孔伟
周良富；蔡晨；王宝坤

专利号：ZL 2012 1 0411015.8

专利申请日：2012年10月25日

专利权人：农业部南京农业机械化研究所

授权公告日：2014年11月05日

本发明经过本局依照中华人民共和国专利法进行审查，决定授予专利权，颁发本证书并在专利登记簿上予以登记。专利权自授权公告之日起生效。

本专利的专利权期限为二十年，自申请日起算。专利权人应当依照专利法及其实施细则规定缴纳年费。本专利的年费应当在每年10月25日前缴纳。未按照规定缴纳年费的，专利权自应当缴纳年费期满之日起终止。

专利证书记载专利权登记时的法律状况。专利权的转移、质押、无效、终止、恢复和专利权人的姓名或名称、国籍、地址变更等事项记载在专利登记簿上。

局长
申长雨

申长雨

中华人民共和国国家知识产权局

2014年11月05日

证书号第2680381号

发明专利证书

发 明 名 称：植保无人机喷洒二相流场室内模拟测试平台及方法

发 明 人：薛新宇；崔龙飞；周立新；秦维彩；张宋超；孙竹；孔伟；蔡晨
丁素明；张玲；金永奎；周良富；顾伟；王宝坤；徐竹凤
丁天航

专 利 号：ZL 2015 1 0051943.1

专利申请日：2015年01月30日

专 利 权 人：农业部南京农业机械化研究所

授权公告日：2017年11月03日

本发明经过本局依照中华人民共和国专利法进行审查，决定授予专利权，颁发本证书并在专利登记簿上予以登记。专利权自授权公告之日起生效。

本专利的专利权期限为二十年，自申请日起算。专利权人应当依照专利法及其实施细则规定缴纳年费。本专利的年费应当在每年01月30日前缴纳。未按照规定缴纳年费的，专利权自应当缴纳年费期满之日起终止。

专利证书记载专利权登记时的法律状况。专利权的转移、质押、无效、终止、恢复和专利权人的姓名或名称、国籍、地址变更等事项记载在专利登记簿上。

局长
申长雨

申长雨

2017年11月03日

证书号第1115761号

发明专利证书

发明名称：一种电磁泵注入式混药装置

发　明　人：薛新宇；孙竹；张宋超；周立新；陈健康；张涛；孔伟；王宝坤

专　利　号：ZL 2010 1 0298655.3

专利申请日：2010年09月28日

专利权人：农业部南京农业机械化研究所

授权公告日：2013年01月02日

本发明经过本局依照中华人民共和国专利法进行审查，决定授予专利权，颁发本证书并在专利登记簿上予以登记。专利权自授权公告日起生效。

本专利的专利权期限为二十年，自申请日起算。专利权人应当依照专利法及其实施细则规定缴纳年费。本专利的年费应当在每年09月28日前缴纳。未按照规定缴纳年费的，专利权自应当缴纳年费期满之日起终止。

专利证书记载专利权登记时的法律状况。专利权的转移、质押、无效、终止、恢复和专利权人的姓名或名称、国籍、地址变更等事项记载在专利登记簿上。

局长 田力普

中华人民共和国国家知识产权局

2013年01月02日

第1页（共1页）

证书号第1733676号

北京市海淀区地方税务局
印花税
代扣专用章
国家知识产权局

发明专利证书

发明名称：一种水稻插秧机施药器及施药控制方法

发　明　人：薛新宇;孙竹;蔡晨;周良富;张宋超;秦维彩;周立新;孔伟
丁素明;吕小兰;张玲;金永奎;王宝坤

专　利　号：ZL 2013 1 0644118.3

专利申请日：2013年12月03日

专利权人：农业部南京农业机械化研究所

授权公告日：2015年07月22日

本发明经过本局依照中华人民共和国专利法进行审查，决定授予专利权，颁发本证书并在专利登记簿上予以登记。专利权自授权公告之日起生效。

本专利的专利权期限为二十年，自申请日起算。专利权人应当依照专利法及其实施细则规定缴纳年费。本专利的年费应当在每年12月03日前缴纳。未按照规定缴纳年费的，专利权自应当缴纳年费期满之日起终止。

专利证书记载专利权登记时的法律状况。专利权的转移、质押、无效、终止、恢复和专利权人的姓名或名称、国籍、地址变更等事项记载在专利登记簿上。

局长
申长雨

中华人民共和国国家知识产权局
2015年07月22日

7. 标准制定情况

ICS 65.060.40
B 91

NY

中华人民共和国农业行业标准

NY/T 3213—2018

植保无人飞机　质量评价技术规范

Technical specification of quality evaluation for crop protection UAS

2018-03-15 发布　　2018-06-01 实施

中华人民共和国农业部　发布

前　　言

本标准按照 GB/T 1.1—2009 给出的规则起草。

本标准由农业部农业机械化管理司提出。

本标准由全国农业机械标准化技术委员会农业机械化分技术委员会(SAC/TC 201/SC 2)归口。

本标准起草单位:农业部南京农业机械化研究所、中国农业机械化协会。

本标准主要起草人:薛新宇、杨林、孙竹、顾伟、刘燕、张宋超、秦维彩。

ICS 65.060.40
B 91
备案号：47359—2014

JB

中华人民共和国机械行业标准

JB/T 9782—2014
代替 JB/T 9782—1999

植物保护机械　通用试验方法

Equipment for crop protection—General test methods

2014-07-09 发布　　　　2014-11-01 实施

中华人民共和国工业和信息化部 发布

前　言

本标准按照GB/T 1.1—2009给出的规则起草。

本标准代替JB/T 9782—1999《植保机械　通用试验方法》，与JB/T 9782—1999相比主要技术变化如下：

——增加了应用计算机图像分析系统进行雾滴直径、雾滴沉积（覆盖）密度、喷雾角及喷雾量分布均匀性的测试方法；

——增加了应用分光光度计，进行药液沉积量及喷雾量分布均匀性的测试方法；

——增加了静电喷头荷电性能测试方法；

——增加了喷雾机防滴性能、与颗粒剂相关的测试方法；

——增加了农药有效利用率的测定方法；

——增加了田间喷雾飘移量的测试方法；

——增加了液力喷雾、航空喷雾作业幅宽的测试方法；

——对容积式泵性能试验及试验方法重新进行了编写与修订；

——删去了金属药箱耐腐蚀试验方法；

——删去了踏板式喷雾器液泵容积效率及手摇风机测定方法；

——删去了机具操作过程中卫生学调查测定方法。

本标准由中国机械工业联合会提出。

本标准由全国农业机械标准化技术委员会（SAC/TC201）归口。

本标准起草单位：农业部南京农业机械化研究所、中国农业机械化科学研究院、苏州农业药械有限公司。

本标准主要起草人：薛新宇、严荷荣、吴萍、汪建。

本标准所代替标准的历次版本发布情况为：

——NJ 204—80、JB/T 9782—1999。

ICS 65.060.40
B 91
备案号：51742—2015

JB

中华人民共和国机械行业标准

JB/T 12451—2015

喷雾式动物防疫消毒机　技术条件

Equipment for spray type animal disinfection machinery
—Technical requirements

2015-10-10 发布　　2016-03-01 实施

中华人民共和国工业和信息化部 发布

前　言

本标准按照GB/T 1.1—2009给出的规则起草。

本标准由中国机械工业联合会提出。

本标准由全国农业机械标准化技术委员会（SAC/TC201）归口。

本标准起草单位：农业部南京农业机械化研究所、苏州农业药械有限公司、中国农业机械化科学研究院。

本标准主要起草人：薛新宇、汪建、刘滢、张玲、严荷荣、张宋超、孙竹。

本标准为首次发布。

8. 文献检索报告

编号：JSNZX2018005

文献检索报告

经江苏省农业科学院科技查新中心检索，查找农业部南京农业机械化研究所薛新宇 2013 -2017 年公开发表的 21 篇论文（7 篇英文论文、14 篇中文论文）被 Web of Science（SCI/SSCI/AHCI/CPCI）、Engineering Village（EI）、CNKI 中国引文数据库中的收录引用情况，详细收录情况见附件。

检索工具：Web of Science（SCI/SSCI/AHCI/CPCI）、Engineering Village（EI）、CNKI 中国引文数据库。

检索类别：收录、引用

检索时限：2013-2018

检索结果：7 篇英文论文均被 SCI 收录，其在 SCI 数据库中总被引频次 28，总他引次数 19。12 篇中文论文被 EI 收录，14 篇中文论文在 CNKI 中国引文数据库中总被引频次 256，总他引次数 226，详见附件（附件盖章有效）。

查新检索单位（盖章）

查新员：程金花　　审核员：

2018 年 01 月 24 日

序号	论文名称	所有作者（通讯作者标*）	期刊名称	年份、卷期及页码	被SCI、EI、ISTP收录情况	影响因子	他引次数
1	Optimization and test for structural parameters of UAV spraying rotary cup atomizer	Zhou Q Q, Xue X Y*, Qin W C, Cai C, Zhou L F	International Journal of Agricultural and Biological Engineering	2017, 10（3）: 78-86	SCI	0.835	0
2	Numerical simulation and experimental verification on downwash air flow of six-rotor agricultural unmanned aerial vehicle in hover	Yang F B, Xue X Y*, Zhang L, Sun Z	International Journal of Agricultural and Biological Engineering	2017, 10(4): 41-53	SCI	0.835	0
3	Downwash distribution of single-rotor unmanned agricultural helicopter on hovering state	Zhang S C, Xue X Y*, Sun Z, Zhou L X, Jin Y K	International Journal of Agricultural and Biological Engineering	2017, 10 (5):14-24	SCI	0.835	0
4	Develop an unmanned aerial vehicle based automatic aerial spraying system	Xue X Y, Lan Y B*, Sun Z, Chang C, W. Clint Hoffmann	Computers and Electronics in Agriculture	2016, 128(201)：58-66	SCI	2.201	2
5	Droplet deposition and control effect of insecticides sprayed with an unmanned aerial vehicle against plant	Qin W C, Qiu B J*, Xue X Y*, Chen C, Xu Z F	Crop Protection	2016, 85, 79-88	SCI	1.834	7
6	Optimization and test for spraying parameters of cotton defoliant sprayer	Qin W C, Xue X Y*, Cui L F, Zhou Q Q, Xu Z F	International Journal of Agricultural and Biological Engineering	2016, 9(4)：63-72	SCI	0.835	2
7	Drift and deposition of ultra-low altitude and low volume application in paddy fielding	Xue X Y, Tu K*, Qin W C, Lan Y B, Zhang H H	International Journal of Agricultural and Biological Engineering	2014, Vol.7(4)23-28	SCI	1.007	8
8	果园变量喷雾技术研究现状与前景分析	周良富, 薛新宇*, 周立新, 张 玲, 丁素明, 常春, 张学进	农业工程学报	2017, 33(23): 80－92	EI	2.11	0
9	大型喷杆及其摆式悬架减振系统动力学特性分析与试验	崔龙飞, 薛新宇*, 丁素明, 乔白羽, 乐飞翔	农业工程学报	2017, 33(09):61-68	EI	2.11	0
10	双钟摆主被动悬架式大型喷雾机喷杆动力学仿真与试验	崔龙飞, 薛新宇*, 丁素明, 顾伟, 陈晨, 乐飞翔	农业机械学报	2017, 48(02):82-90	EI	1.748	1
11	基于EBF神经网络模型的喷雾机吊喷分禾器参数优化	崔龙飞, 薛新宇*, 秦维彩	农业机械学报	2016, (5)：62-69	EI	1.748	1
12	喷雾机喷杆结构形状及截面尺寸优化与试验	陈晨, 薛新宇*, 顾伟, 崔龙飞, 秦维彩, 周良富	农业工程学报	2015, (09):50-56	EI	2.11	4

13	手持式风送授粉机工作参数优化与试验	丁素明, 薛新宇*, 方金豹, 孙竹, 蔡晨, 周良富, 秦维彩	农业工程学报	2015, (08):68-75	EI	2.11	10
14	射流式在线混药装置汽蚀特性数值分析与试验	周良富, 周立新, 薛新宇*, 孔伟	农业工程学报	2015, (07):60-65	EI	2.11	4
15	N-3型农用无人直升机航空施药飘移模拟与试验	张宋超, 薛新宇*, 秦维彩, 孙竹, 丁素明, 周立新	农业工程学报	2015, (03):87-93	EI	2.11	16
16	无人直升机喷雾参数对玉米冠层雾滴沉积分布的影响	秦维彩, 薛新宇*, 周立新, 张宋超, 孙 竹, 孔 伟, 王宝坤	农业工程学报	2014, 30(5):50-56	EI	2.11	53
17	手持式风送授粉机研制与试验	丁素明, 薛新宇*, 蔡晨, 秦维彩, 方金豹, 孙竹	农业工程学报	2014, 30(13):20—27	EI	2.11	5
18	CFD技术在果树风送喷雾中的应用与前景分析	周良富, 薛新宇*, 贾卫东, 丁素明, 孙竹	排灌机械工程学报	2014 Vol.32(9): 783-787		0.986	7
19	美国农业航空技术现状和发展趋势分析	薛新宇, 兰玉彬*	农业机械学报	2013, 44(5):194-201	EI	1.748	79
20	N-3型无人直升机施药方式对稻飞虱和稻纵卷叶螟防治效果的影响	薛新宇, 秦维彩, 孙竹, 张宋超, 周立新, 吴萍	植物保护学报	2013, 40(3):273-278		0.964	31
21	无人机高浓度施药对水稻品质的影响	薛新宇, 屠康*, 兰玉彬, 秦维彩, 张玲	农业机械学报	2013, 44(12):74-79	EI	1.498	15
					合计	33.954	

1. Develop an unmanned aerial vehicle based automatic aerial spraying system. Xue Xinyu, Yubin Lan*, Sun Zhu, Chang Chun, W. Clint Hoffmann. Computers and Electronics in Agriculture. 2016，128(201)：58-66 SCI 收录 **if =2.201**

SCI 总被引频次：3 SCI 他引：2 次

（1）Downwash distribution of single-rotor unmanned agricultural helicopter on hovering state. Zhang Songchao; Xue Xinyu; Sun Zhu; 等. INTERNATIONAL JOURNAL OF AGRICULTURAL AND BIOLOGICAL ENGINEERING. 卷: 10 期: 5 页: 14-24 出版年: SEP 2017

(2) Current status and future trends of precision agricultural aviation technologies. Lan, Yubin; Chen Shengde; Fritz, Bradley K. INTERNATIONAL JOURNAL OF AGRICULTURAL AND BIOLOGICAL ENGINEERING. 卷: 10 期: 3 页: 1-17 出版年: MAY 2017

(3) Effect of wind field below unmanned helicopter on droplet deposition distribution of aerial spraying. Chen Shengde; Lan, Yubin; Li Jiyu; 等. INTERNATIONAL JOURNAL OF AGRICULTURAL AND BIOLOGICAL ENGINEERING. 卷: 10 期: 3 页: 67-77 出版年: MAY 2017

2. Droplet deposition and control effect of insecticides sprayed with an unmanned aerial vehicle against plant hoppers. Qin Weicai, Qiu Baijing, Xue Xinyu*, Chen Chen, Xu Zhufeng, Zhou Qingqing. Crop Protection. 2016, 85:79-88. SCI 收录 **if =1.834**

SCI 总被引频次: 8 SCI 他引：7 次

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（2） Numerical simulation and experimental verification on downwash air flow of six-rotor agricultural unmanned aerial vehicle in hover. Yang Fengbo; Xue Xinyu; Zhang Ling; 等. INTERNATIONAL JOURNAL OF AGRICULTURAL AND BIOLOGICAL ENGINEERING. 卷: 10 期: 4 页: 41-53 出版年: JUL 2017

（3）Current status and future trends of precision agricultural aviation technologies. Lan, Yubin; Chen Shengde; Fritz, Bradley K. INTERNATIONAL JOURNAL OF AGRICULTURAL AND BIOLOGICAL ENGINEERING. 卷: 10 期: 3 页: 1-17 出版年: MAY 2017

（4）Recent development of unmanned aerial vehicle for plant protection in East Asia. He Xiongkui; Bonds, Jane; Herbst, Andreas; 等. INTERNATIONAL JOURNAL OF AGRICULTURAL AND BIOLOGICAL ENGINEERING. 卷: 10 期: 3 页: 18-30 出版年: MAY 2017

（5）Droplets movement and deposition of an eight-rotor agricultural UAV in downwash flow field. Tang Qing; Zhang Ruirui; Chen Liping; 等. INTERNATIONAL JOURNAL OF AGRICULTURAL AND BIOLOGICAL ENGINEERING. 卷: 10 期: 3 页: 47-56 出版年: MAY 2017

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（7）Effect of wind field below unmanned helicopter on droplet deposition distribution of aerial spraying. Chen Shengde; Lan, Yubin; Li Jiyu; 等. INTERNATIONAL JOURNAL OF AGRICULTURAL AND BIOLOGICAL ENGINEERING. 卷: 10 期: 3 页: 67-77 出版年: MAY 2017

（8）Optimization of Pesticide Spraying Tasks via Multi-UAVs Using Genetic Algorithm. Luo, He; Niu, Yanqiu; Zhu, Moning; 等. MATHEMATICAL PROBLEMS IN ENGINEERING. 文献号: 7139157 DOI: 10.1155/2017/7139157 出版年: 2017

3. Drift and deposition of ultra-low altitude and low volume application in paddy field. Xue Xinyu, Tu Kang*, Qin Weicai, Yubin Lan, Huihui Zhang. International Journal of Agricultural and Biological Engineering. 2014，7(4)：23-28. SCI 收录 **if =1.007**

SCI 总被引频次:14 SCI 他引: 8

（1）Downwash distribution of single-rotor unmanned agricultural helicopter on hovering state. Zhang Songchao; Xue Xinyu; Sun Zhu; 等. INTERNATIONAL JOURNAL OF AGRICULTURAL AND BIOLOGICAL ENGINEERING. 卷: 10 期: 5 页: 14-24 出版年: SEP 2017

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（3）Numerical simulation and experimental verification on downwash air flow of six-rotor agricultural unmanned aerial vehicle in hover. Yang Fengbo; Xue Xinyu; Zhang Ling; 等. INTERNATIONAL JOURNAL OF AGRICULTURAL AND BIOLOGICAL ENGINEERING. 卷: 10 期: 4 页: 41-53 出版年: JUL 2017

（4）Radiative transfer models (RTMs) for field phenotyping inversion of rice based on UAV hyperspectral remote sensing. Yu Fenghua; Xu Tongyu; Du Wen; 等. INTERNATIONAL JOURNAL OF AGRICULTURAL AND BIOLOGICAL ENGINEERING. 卷: 10 期: 4 页: 150-157 出版年: JUL 2017

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（7）Effect of wind field below unmanned helicopter on droplet deposition distribution of aerial spraying. Chen Shengde; Lan, Yubin; Li Jiyu; 等. INTERNATIONAL JOURNAL OF AGRICULTURAL AND BIOLOGICAL ENGINEERING. 卷: 10 期: 3 页: 67-77 出版年: MAY 2017

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（9）DROPLET DISTRIBUTION AND CONTROL AGAINST CITRUS LEAFMINER WITH UAV SPRAYING. Zhang Pan; Wang Kejian; Lyu Qiang; 等. INTERNATIONAL JOURNAL OF ROBOTICS & AUTOMATION 卷: 32 期: 3 页: 299-307 出版年: 2017

（10）Effects of citrus tree-shape and spraying height of small unmanned aerial vehicle on droplet distribution. Zhang Pan; Deng Lie; Lyu Qiang; 等. INTERNATIONAL JOURNAL OF AGRICULTURAL AND BIOLOGICAL ENGINEERING. 卷: 9 期: 4 页: 45-52 出版年: JUL 2016

（11）Droplet deposition and control effect of insecticides sprayed with an unmanned aerial vehicle against plant hoppers. Qin, Wei-Cai; Qiu, Bai-Jing; Xue, Xin-Yu; 等. CROP PROTECTION. 卷: 85 页: 79-88 出版年: JUL 2016

（12）Optimization of working parameters for puddling and flatting machine in paddy field. Xu Chunlin; Zhang Chengliang; Li Lianhao; 等. INTERNATIONAL JOURNAL OF AGRICULTURAL AND BIOLOGICAL ENGINEERING. 卷: 9 期: 3 页: 88-96 出版年: MAY 2016

（13）Evaluating droplet distribution of spray-nozzles for dust reduction in livestock buildings using machine vision. Mehdizadeh, Saman Abdanan; Banhazi, Thomas M. INTERNATIONAL JOURNAL OF AGRICULTURAL AND BIOLOGICAL ENGINEERING. 卷: 8 期: 5 页: 58-64 出版年: OCT 2015

（14）Control design of an unmanned hovercraft for agricultural applications. Garcia, Deyka I.; White, Warren N. INTERNATIONAL JOURNAL OF AGRICULTURAL AND BIOLOGICAL ENGINEERING. 卷: 8 期: 2 页: 72-79 出版年: APR 2015

4. Optimization and test for structural parameters of UAV spraying rotary cup atomizer. Zhou Qingqing, Xue Xinyu*, Qin Weicai, Cai Chen, Zhou Liangfu. International Journal of Agricultural and Biological Engineering 2017, 10(3):78-86.

   SCI 收录 **if=0.835**

   SCI 总被引频次：0 ； SCI 他引：0 次

5. Numerical simulation and experimental verification on downwash air flow of six-rotor agricultural unmanned aerial vehicle in hover. Yang Fengbo, Xue Xinyu*, Zhang Lin, Sun Zhu. International Journal of Agricultural and Biological Engineering. 2017, 10(4):41-53.

SCI 收录　**if=0.835**

SCI 总被引频次：1； SCI 他引：0 次

（1）Downwash distribution of single-rotor unmanned agricultural helicopter on hovering state. Zhang Songchao; Xue Xinyu; Sun Zhu; 等. INTERNATIONAL JOURNAL OF AGRICULTURAL AND BIOLOGICAL ENGINEERING. 卷: 10 期: 5 页: 14-24 出版年: SEP 2017

6. Downwash distribution of single-rotor unmanned agricultural helicopter on hovering state. Zhang Songchao, Xue Xinyu*, Sun Zhu, Zhou Lixin, Jin Yongkui. International Journal of Agricultural and Biological Engineering. 2017, 10(5):14-24.

SCI 收录　**if=0.835**

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（1）A novel detection method of spray droplet distribution based on LIDARs. Zheng Yongjun; Yang Shenghui; Lan, Yubin; 等. INTERNATIONAL JOURNAL OF AGRICULTURAL AND BIOLOGICAL ENGINEERING. 卷: 10 期: 4 页: 54-65 出版年: JUL 2017

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8. 美国农业航空技术现状和发展趋势分析　薛新宇,兰玉彬*　农业机械学报 2013, 44(5):194-201.

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[1]航空静电喷雾技术现状及其在植保无人机中应用的思考[J]. 刘武兰,周志艳,陈盛德,罗锡文,兰玉彬. 农机化研究. 2018(05)

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[5]我国农用无人机发展概况与展望[J]. 杨陆强,果霖,朱加繁,高志超,周体全,喻自荣,彭继文,张汝坤. 农机化研究. 2017(08)

[6]小型植保无人机喷雾参数对橘树冠层雾滴沉积分布的影响[J]. 陈盛德,兰玉彬,周志艳,廖娟,朱秋阳. 华南农业大学学报. 2017(05)

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[8]大载荷植保无人直升机喷雾气液两相流动数值模拟[J]. 王军锋,徐文彬,闻建龙,王晓英,罗博韬. 农业机械学报. 2017(09)

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EI 收录　if =2.110

总被引频次：0　他引：0

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EI 收录　if =1.748

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EI 收录 if =2.110
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EI 收录 if =2.110

总被引频次：6 他引：5

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EI 收录 if =2.110

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