Drift potential of UAV with adjuvants in aerial applications

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Abstract: The reduction of pesticide aerial spraying drift is still one of the major challenges in modern agriculture. The aim of this study was to evaluate the drift potential of different types of unmanned aerial vehicle (UAV) and adjuvant products for reducing spray drift in aerial applications. Three types of UAV (3WQF120-12 and 3CD-15 fuel oil powered single-rotor UAV and HY-B-15L battery powered single-rotor UAV) were selected in this study with regular application parameters to compare each spray drift, and 3WQF120-12 fuel oil powered UAV was selected to quantify spray drift of 6 adjuvants dissolved in water under field conditions. Solutions were marked with brillant sulfoflavin dye (BSF) at 0.1%. Petri dishes and rotary impactors were used to collect airborne and sediment drift, respectively. Drift deposits were evaluated by spectrophotometry in order to quantify deposits. The results showed that when the flight height was 1.5-2.0 m above the crop at the flight speed of 4-5 m/s and the average wind speed of 1.63-1.73 m/s, 3WQF120-12 fuel oil powered UAV had lower drift potential than the other two types; $D_{V0.5}$ and percentage of droplets with diameter $\leq 75\ \mu m$ had very significant effects on spray drift percentage (p=0.01); the risk of drift in agricultural spraying could be significantly decreased not only by reducing the percentage of fine droplets but also by changing droplet spectra. Compared to water, Silwet DRS-60, ASFA+B, T1602, Break-thru Vibrant, QF-LY and Tmax could reduce by 65%, 62%, 59%, 46%, 42%, and 19% spray drift, respectively. when water without adjuvants were sprayed, 90% of drift droplets were located within a range of 10.1 m of the target area while with 0.8% Silwet DRS-60 adjuvant in water, the distance was shortened to 6.4 m.

Keywords: spray drift, UAV, adjuvant, aerial application, drift potential evaluation, droplet size
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1 Introduction

Aerial application plays an important role in promoting agricultural production and protecting environment due to its flexibility, convenience and high work efficiency. Aircraft are able to apply agricultural products rapidly over large areas within narrow optimum application windows. When crop height and irrigated areas restrict the passage of wheeled vehicles, aircraft are able to place pesticides strategically on crops in response to economic thresholds, without contributing to soil compaction and breakdown[1,2]. However, spray drift from the aerial application of pesticides has been recognized as one of the biggest problems for the environment[3,4]. Factors as environmental conditions, equipment design issues, application parameters and numerous interactions make it difficult to completely understand drift related issues[5,6]. Except for nozzle selection and operation, spray adjuvants are considered as one of the auxiliary factor for drift reduction by aerial applicators[7-9].

Adjuvants can minimize or eliminate many spray application problems by controlling physical and chemical properties with specific functions, including wetting, spreading, sticking, reducing evaporation, volatilization and also spray drift[10]. Deviation in absolute values of spray droplet size and drift reduction are possible for different products of the same formulation type. For formulation types, the knowledge of the composition is required to evaluate its impact on spray characteristics. The potential of a formulated product to reduce spray drift can be identified when measuring the spray droplet size spectra at relevant concentrations. To choose the proper adjuvant can be one of the main practices adopted to reduce the negative effects of the spray drift, as well as improving safety and efficacy in pesticide applications[11,12].

There is limited technical literature on aerial performance of drift reduction since much of the previous research has focused on ground application systems. Determination of spray drift using boom sprayers has been studied extensively in a series of field trials and crops. The data include the variability of spray drift between different fields (field trials). Several studies have been conducted in the last few years to evaluate and quantify the effect of the different parameters involved in the process; nevertheless, it is a large effort to define a classification method for spray techniques, which always vary greatly because of the influence of environmental conditions[13-15]. To solve the problem, previous studies has been conducted in wind tunnel to characterize the effect

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of operating parameters on the risk of spray drift under controlled conditions, which could not be repeated and compared under field conditions due to climatic variations[16-18]. However, values under real drift conditions can only be obtained in field experiments.

Researches of agricultural spraying in China were mostly based on the deposition of unmanned aerial vehicles (UAVs). Zhang et al.[19] evaluated droplets deposition of WPH642 unmanned aircraft with different application parameters on rice canopy, Xue et al.[20,21] measured the efficacy, spray deposition and aerial drift of N-3 UAV in paddy field. Huang et al.[22] investigated droplet size and deposition characteristics of a low drift nozzle for aerial application at different altitudes. Kirk[3] did an extensive field study using four spray mixes of glyphosate from three different formulations to determine relative drift propensity of the spray mixes from the different formulations. As research on spray drift distribution with unmanned helicopters using adjuvants in wheat crops has not been reported, the aim of this study is to compare spray drift of three types of UAVs and to evaluate the drift potential of 6 different adjuvants using 3WQF120-12 UAV from the downwind direction on wheat canopy in order to provide a theoretical basis and data supporting to spray drift control in agricultural production of China.

2 Materials and methods

2.1 Specifications of UAVs

Two fuel oil powered single-rotor UAV 3WQF120-12 (Anyang Quanfeng Biological Technology Co., Ltd.), 3CD-15 (Wuxi Hanhe Aviation Technology Co., Ltd) and one battery powered single-rotor UAV HY-B-15L (Shenzhen Gaoke Co., Ltd.) were used in the experiments. The three UAVs are shown in Figure 1. The specifications of the three UAVs are listed in Table 1.

a. UAV 3WQF120-12 (fuel oil powered UAVs),
Anyang Quanfeng Biological Technology

b. UAV 3CD-15 (fuel oil powered UAVs), Wuxi Hanhe Aviation Technology

c. UAV HY-B-15L (battery powered UAV), Shenzhen Xinnong Gaoke

Figure 1 The three UAVs chosen for the research

Table 1 Specifications of the UAVs

Parameters	HY-B-15L	3CD-15	3WQF120-12
Power	Battery	Fuel oil	Fuel oil
Flight height/m	1.5	2	2
Flight speed/m s^{-1}	5	4	5
Spray width/m	5	5	4.5
Nozzle type	TR80-015	Turbo Teejet-01	LU120-02
Nozzle numbers	5	4	2
Boom length/mm	2350	1300	1350
Max loading capacity/L	15	15	12
Rotor length/mm	2460	2240	2410

2.2 Adjuvants

UAVs in Table 1 were selected in this article with regular application parameters to compare each spray drift at first. Then 3WQF120-12 fuel oil powered UAV was selected to quantify spray drift of 6 adjuvants with recommended concentration as shown in Table 2.

Table 2 Adjuvants

Name	Main ingredient	Manufacturer	Concentration	Main function
Tmax	Methylated vegetable oil	Grand AgroChem, China	1%	Anti-evaporation
QF-LY	Organosilicon	Quanfeng, China	0.5%	Anti-evaporation and anti-drift
Break-thru Vibrant	Non-ionic organic surfactant	Evonik, Germany	0.2%	Anti-drift
T1602	Methylated vegetable oil	Grand AgroChem, China	1%	Anti-evaporation
ASFA+B	Methylated vegetable oil & organosilicon	Aishang, China	1%	Anti-evaporation and anti-drift
Silwet DRS-60	Organosilicon	Momentive, USA	0.8%	Anti-drift

2.3 Experimental design

2.3.1 Field test of UAVs

This experiment was implemented in the wheat field of Neihuang village, Anyang City, Henan Province, China. The plots were planned as a rectangular land, without buildings or trees around. Weather station ZENO-3200 (Pri-eco Company Limited, USA) was used to record wind speed and wind direction from 6m above the ground and Testo 350-XL (Testo SE & Co. KGaA, Germany) was used to record temperature and humility. The spray solution was 0.1% fluorescence tracer BSF (brillant sulfoflavin dye, Chroma-Gesellschaft Schmid, Germany) in water.

Figure 2 gave the arrangement of drift collectors at the spray area. Petri dishes and rotary impactors (Leading edge, USA) were used to collect airborne and sediment drift, respectively. Each five petri dishes were put 1 m, 3 m, 5 m, 10 m, 15 m and 20 m away from the spray area according to ISO (International Organization for Standardization) standard 22866 and rotary impactors were put 5 m, 10 m and 20 m away from the spray area, each distance with four in a row vertically with the distance 1 m, 2 m, 3 m and 4 m above the ground. Water sensitive paper (WSP) was used to measure diameters of droplet size of three UAVs. Three lines of WSPs were manipulated perpendicular to flight direction (lateral direction) in the center of testing region, and the length of each line was 15 m. The interval of WSPs was 1.0 m. The height of WSPs equals to wheat plants. The direction of UAV was perpendicular to the wind direction and the drift collectors were arranged along the direction of wind. In order to make the spray more stable, the UAV took off and was hovering

20 m from the spray area, and stopped spraying 10 m away. Spectrophotometry SFM25 (Kontron, Germany) was used to determinate fluorescence of each collector. Drift deposition on a unit area could be determined according to ISO standard 24253-1.

The formula of deposition is:

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

$$\beta_{dep\%}=\frac{\beta_{dep}}{(\beta_V/100)}\times 100$$

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

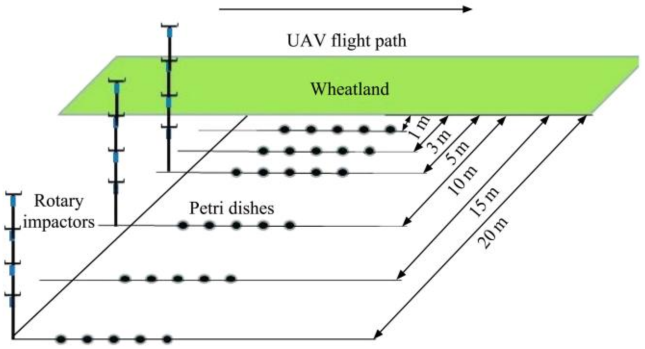


Figure 2 Layout of field sampling for spray drift test

2.3.2 Droplet size spectra test of adjuvants

A study to measure droplet size spectra of nozzle LU120-02 under pressure 0.3 MPa (nozzle of 3WQF120-12 UAV) was conducted at the Center for Chemical Application Technology (CCAT) of China Agricultural University in Beijing, China. Liquid with adjuvants types and concentrations used in the study are listed in Table 2. OMEC DP-02(OMEC Instrument Co., Ltd. Zhuhai, China) was used to measure droplet diameters of spray liquid with 6 adjuvants and water alone. Each randomly selected nozzle was assigned a number (1-3) to ensure repeatability of that given nozzle to allow for appropriate data comparisons. The laser diffraction instrument was 50 cm from the nozzle, a distance that allows for sufficient breakup of the liquid sheet. The nozzles were operated on an actuated arm in a downward direction with their spray plume passing through the beam for 15 s per measurement. The volumetric droplet size spectra parameters selected for data interpretation were the Dv$_{0.1}$, Dv$_{0.5}$, and Dv$_{0.9}$, relative span (RS), and the percentage of the spray volume contained in droplets with a diameter below 75 μm and 100 μm. The volume median diameter (Dv$_{0.5}$) is the diameter at which half of the volume of droplets are contained in droplets of larger or smaller diameter to help classify sprays, and understand the size classification of each. The Dv$_{0.1}$ is the diameter at which 10% of the volume of droplets contained in droplets at or below that diameter, the Dv$_{0.9}$ is the diameter at which 90% of the droplets contained in droplets at or below that diameter. The RS is calculated using the equation below:

$$RS=\frac{D_{V0.9}-D_{V0.1}}{D_{V0.5}}$$

3 Results and analysis

3.1 Drift potential of UAVs

The average wind speed, wind direction, air temperature and relative humility of the test are listed in Table 3.

Table 3 Meteorological data

UAV	Average wind speed/m s^{-1}	Air temperature/℃	Relative humility/%	Wind description
HY-B-15L	1.63	28.9	54.7	North, steady
3CD-15	1.64	30.9	41.4	North, steady
3WQF120-12	1.73	28.5	46.7	North, steady

In the test the flight height was 1.5-2.0 m above the crop and the flight speed was 4.0-5.0 m/s (Table 1). The average wind speed was 1.63-1.73 m/s, temperature was 28.5℃-30.9℃, and the relative humility was 41.4%-54.7% (Table 3). Droplet size of UAVs is shown in Table 4 and sediment spray drift percentage at different distances is shown in Figure 3. Spray drift percentage of UAVs decreased as downwind distance increased; spray drift volume of HY-B-15L, 3CD-15 and 3WQF120-12 accounted for 23.0%, 9.4% and 2.4% of the total spray volume, respectively.

The DepositScan software was used to measure the droplet distribution and droplet size on WSPs, and the results are shown in Table 4. The result of spray drift percentage at different distances of UAVs is shown in Figure 3. D$_{V0.5}$ of HY-B-15L and 3CD-15 UAV were 245 μm and 324 μm while spray drift percentage of HY-B-15L was 2.4 times as much as 3CD-15, which meant that volume median diameter (VMD) was one of the factors influenced spray drift; the larger VMD of droplet drift was, the lower spray drift percentage could be. D$_{V0.5}$ of HY-B-15L and 3WQF120-12 UAV were 245 μm and 243 μm which was similar to each other while spray drift percentage of HY-B-15L was 9.6 times as much as 3WQF120-12. From Table 1, the boom length of HY-B-15L UAV was 95% of rotor length while boom length of 3WQF120-12 UAV was 56% of rotor length which meant that despite of VMD, boom length of UAV was also one of the main factors that could influence spray drift. When boom length is too long, spray droplet drift could be easily affected by down was air around the rotor and could cause more spray drift.

Table 4 Droplet size of UAVs

UAV	D$_{V0.1}$/μm	D$_{V0.5}$/μm	D$_{V0.9}$/μm
HY-B-15L	133	245	418
3CD-15	157	324	543
3WQF120-12	143	243	356

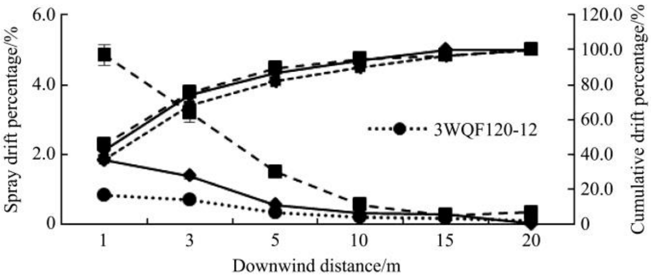
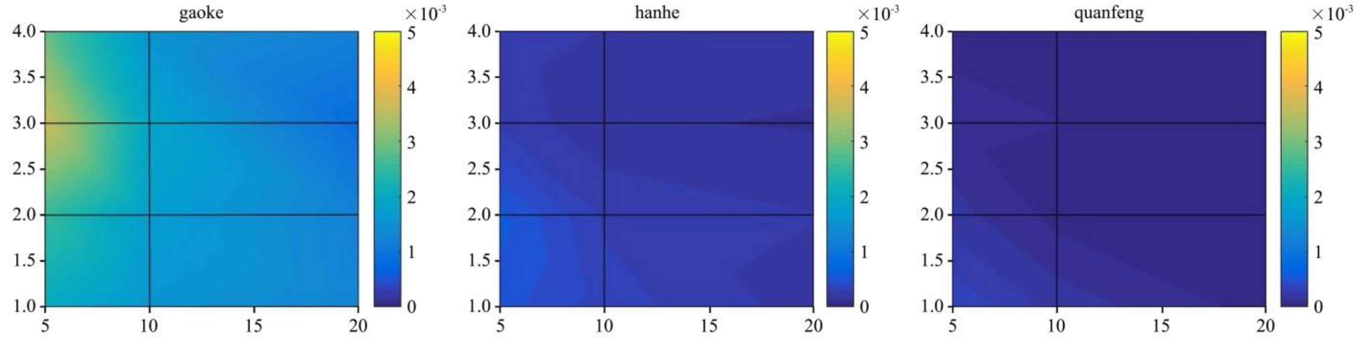


Figure 3 Spray drift percentage at different distances of UAVs

Software MATLAB was used to analyze airborne drift 1 m, 2 m, 3 m and 4 m vertically above the ground with downwind distance 5 m, 10 m and 20 m, respectively. As seen from Figure 4, airborne spray drift distribution of three UAVs could be seen clearly. Airborne spray drift of HY-B-15L was higher than that of the other two UAVs which matched the result of sediment spray drift of the three UAVs.

From vertical distance, the flight height of HY-B-15L, 3CD-15 and 3WQF120-12 was 1.5 m, 2 m and 2 m while spray drift height was below 4 m, 3 m and 2.5 m, respectively. Airborne spray drift percentage of HY-B-15L, 3CD-15 and 3WQF120-12 was 25.0%, 4.2% and 2.5%, respectively.

From downwind distance, spray drift droplets of HY-B-15L UAV flew up first at 5m downwind distance and then settled down at 10 m distance, it might because drift droplets around the rotor were affected by the crosswind so they were taken away from the UAV which caused more spray drift settled down far away downwind distance. For 3CD-15 and 3WQF120-12 UAV, spray drift droplets were settled down at 5 m downwind distance, but the droplets velocity of 3CD-15 were faster than 3WQF120-12, might because the $D_{V0.5}$ of 3CD-15 was much bigger than 3WQF120-12. Airborne drift result could match with the sediment drift result, with the two results, spray drift distribution and regularity could be known.



a. HY-B-15L b. 3CD-15 c. 3WQF120-12

Figure 4 Airborne spray drift distribution of UAVs

3.2 Adjuvants to mitigate spray drift

3WQF120-12 fuel oil powered UAV was selected to quantify spray drift of 6 adjuvants (1% Tmax, 1% T1602, 1% ASFA+B, 0.2% Break-thru Vibrant, 0.8% Silwet DRS-60, 0.5% QF-LY) dissolved in water under field conditions. The average wind speed, wind direction, air temperature and relative humility of the test are listed in Table 5.

It is fundamentally important to measure droplet size and the size distribution to understand the environmental and the biological fate of spray droplets. The amount of spray drift is usually related to the percentage of fine spray droplets. The smaller a spray droplet, the longer it remains airborne and the higher the possibility for it to be carried away by crosswind. Droplets with diameter ≤75 μm or 100 μm contribute significantly to drift losses[23,24]. The droplet size of adjuvants is shown in Table 6.

Table 5 Meteorological data of adjuvants test

UAV	Average wind speed/m s^{-1}	Air temperature / ℃	Relative humility/%	Wind description
Water (blank)	6.36	28.8	44.4	North, steady
Tmax	6.05	29.5	45.3	North, steady
QF-LY	5.12	28.9	47.8	North, steady
Break-thru vibrant	6.00	29.5	44.4	North, steady
T1602	4.54	30.2	44.8	North, steady
ASFA+B	4.58	29.6	46.4	North, steady
Silwet DRS-60	7.29	29.3	44.4	North, steady

Table 6 Droplet size of adjuvants

Name	$D_{V0.1}$/μm	$D_{V0.5}$/μm	$D_{V0.9}$/μm	≤75 μm/%	≤100 μm/%	RS
Water (blank)	79.18	163.49	292.46	8.63	18.30	1.30
Tmax	98.53	190.01	348.17	6.09	10.49	1.31
QF-LY	100.16	190.10	328.19	5.01	11.50	1.20
Break-thru Vibrant	97.25	190.40	334.08	4.53	10.98	1.24
T1602	102.56	212.02	361.74	3.88	9.28	1.22
ASFA+B	115.02	211.32	374.93	4.65	6.32	1.23
Silwet DRS-60	87.02	206.10	425.64	6.32	14.26	1.64

As seen in Figure 5, six adjuvants in the test all contributed to reduce spray drift percentage. Compared to water, Silwet DRS-60, ASFA+B, T1602, Break-thru Vibrant, QF-LY and Tmax could reduce 65%, 62%, 59%, 46%, 42%, and 19% spray drift , respectively. When spray liquid was only water, 90% of the drift was concentrated within 10.1 m of the spray area while the distance is shortened to 6.4 m when Silwet DRS-60 was added.

From Table 6, relative span (RS) of Silwet DRS-60 was 1.64, which was much higher than the other five adjuvants and implied a wide droplet spectra of Silwet DRS-60. RS was generally not significantly different between the five adjuvants. Droplets with diameter ≤75 μm and 100 μm of Silwet DRS-60 was much higher than the other five adjuvants which indicated that Silwet DRS-60 mitigated spray drift percentage by making droplet spectra wide instead of reducing the percentage of fine droplets.

Table 7 indicated that spray drift percentage of other five adjuvants despite of Silwet DRS-60 was well related to $D_{V0.1}$, $D_{V0.5}$, $D_{V0.9}$ and percentage of droplets with diameter ≤75 μm and 100 μm: percentage of droplets with diameter ≤75 μm and 100 μm was positively related to the spray drift percentage and was negatively related to the spray drift percentage. $D_{V0.5}$ and percentage of droplets with diameter ≤75 μm had very significant effects on spray drift percentage (p=0.01). Spray drift percentage increased as percentage of droplets with diameter ≤75 μm increased, it increased as $D_{V0.5}$ of droplets decreased.

The results above indicated that the selection of appropriate class and concentration of adjuvants can significantly decrease the risk of drift in agricultural spraying not only by reducing the percentage of fine droplets and also by widening droplet spectra.

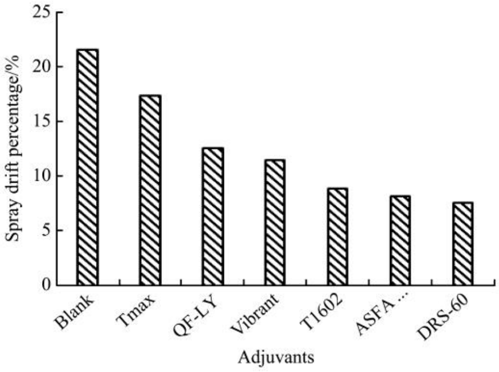


Figure 5 Spray drift percentage of adjuvants

Table 7 Regression result of each factor with cumulative drift percentage

Independent variable (x)	$D_{V0.1}$/μm	$D_{V0.5}$/μm	$D_{V0.9}$/μm	≤75 μm/%	≤100 μm/%
Correlation coefficient	-0.87	-0.92	-0.82	0.94	0.87
Probability	0.02	0.01	0.05	0.01	0.02

4 Conclusions

1) In the condition that the flight height was 1.5-2.0 m above the crop, the flight speed was 4-5 m/s and the average wind speed was 1.63-1.73 m/s, sediment spray drift volume of HY-B-15L, 3CD-15 and 3WQF120-12 UAV accounted for 23.0%, 9.4% and 2.4% spray volume while airborne spray drift percentage of the three UAVs was 25.0%, 4.2% and 2.5%, respectively, which shows that 3WQF120-12 fuel oil powered UAV has lower drift potential than the other two types.

2) $D_{V0.5}$ and percentage of droplets with diameter ≤75 μm had very significant effects on spray drift percentage (p=0.01). Spray drift percentage increased as percentage of droplets with diameter ≤75 μm increased and as $D_{V0.5}$ of droplets decreased.

3) The selection of appropriate class and concentration of adjuvants can significantly decrease the risk of drift in agricultural spraying not only by reducing the percentage of fine droplets but also by widening droplet spectra. In this test, Silwet DRS-60, ASFA+B, T1602, Break-thru Vibrant, QF-LY and Tmax could reduce 65%, 62%, 59%, 46%, 42%, and 19% spray drift compared to water, respectively.

4) In this test, 90% of spray drift of 3WQF120-12 Fuel Oil Powered UAV was within 10.1 m from the spray area. With 0.8% Silwet DRS-60 adjuvant, the distance was shortened to 6.4 m. It provides a reference for the division of buffer zone in aerial spraying.

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