Field evaluation of a Tri-Set spray nozzle for aerial application and discussion on release of biological control agents

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Abstract: Efficiency and efficacy of aerial application of liquid formations has been studied extensively in terms of optimal nozzle/atomizer setups, adjuvant mixes, weather conditions, and aerial spray release heights. In past studies, we have evaluated CP-11 flat-fan nozzles to assess impact factors of in-swath and downwind deposition from aerial spray application, and a solid stream radial Accu-Flo nozzle to determine penetration of the spray within crop canopy. When applying liquid tank mixes from aerial platforms, there are numerous nozzle types available with differing spray characteristics. More information is needed, however, on the ability of aerial delivery systems to effectively apply biological agents. The release of non-toxigenic A. flavus into corn fields has shown promise as a biological control agent for aflatoxin producing strains of the fungus. However, the application of a coarse granule to mature, two-meter-tall corn is a challenge. Thus, there would be substantial advantages to a liquid formulation with necessary identification of appropriate adjuvants to disperse the highly hydrophobic spores of A. flavus. This paper presents the experiment and preliminary data analysis of testing and evaluating Davidon tri-set nozzles under various nozzle configurations, and discusses what we need to know for effective use of different nozzles for potential application of biological control agents, especially Afla-Guard®, a commercially available product containing non-toxigenic A. flavus as a biological control agent, and related products into corn fields.

Keywords: aerial application, crop protection, nozzle evaluation, biological control agents
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1 Introduction

Application efficiency and efficacy from aerial platforms to release liquid formations has been studied extensively for crop protection[1-3]. Conventionally, the aerial platforms for agricultural spray application are mostly on fixed wing agricultural aircraft and some rotary helicopters, and in the past few years unmanned aerial vehicle (UAV) is rapidly emerging for crop protection worldwide. As the statistics of the Federal Aviation Administration (FAA) (Washington, DC, USA), in the U.S. there are approximately 3,600 agricultural aircraft in service[4]. A 2012 survey report by the NAAA indicates approximately 87% of the agricultural aircraft fleet in the U.S. is composed of fixed wing aircraft and helicopters comprise the remaining 13%[4]. With this capacity, now, every year aerial application pilots treat approximately 127 million acres of cropland in the U.S., which equates to 28% of all commercial cropland in the country[5]. Moore[6] reports that now 4% of aerial applications in the U.S. now use unmanned aircraft systems in their operations. Japan developed the Yamaha technology in 1980s for UAV (Unmanned Aerial Vehicle) aerial application to conduct crop protection[7]. In early 2010s China began to rapidly develop UAV plant protection technology[8]. Although "In the U.S. … there is no commercial use of this technology—it's strictly a research and development effort" in three or five years ago[9], now more research and industrial efforts have been made to push forward this technology into practice. However, considering powerful aerial and ground spray application capacity established and the factors of payload, speed, coverage, penetration, which are not comparable from UAVs, and the average farm size and regulation restrictions[10], in the U.S. fixed wing aircraft will still be the main power of aerial application.

One of the most problems in aerial application is to reduce off-target drift and increase in-swath deposition to balance the two aspects to maximize the efficiency and efficacy of the spray application. To understand the performance of spray application, nozzles test and evaluation are needed. Using laser diffraction spray droplets of a nozzle can be measured allow users to create a desired droplet size through selected nozzle, operating pressures, and adjuvants to maximize effectiveness of agrochemicals with minimum negative impact on the surrounding environment[11]. Wind tunnel can be used to compare two different nozzles[12], to establish reference nozzles[13], and to provide guideline data for federal government to establish testing protocols for nozzles, agrochemicals, application parameters, and combinations for applying agrochemicals by certified individuals in the country[14]. Most practically, nozzles are installed on the booms and tested on aircraft when it flies over crop conditions. This kind of nozzle test and evaluation is typically conducted in terms of optimal nozzle/atomizer setups, adjuvant mixes, weather conditions, and aerial spray release heights. In College Station, Texas, Lan et al.[15] tested CP-11TT flat fan nozzles (CP Products Co., Tempe,

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Arizona, USA) set to the number 15 orifice and 75-degree deflection on an Air Tractor 402B (Air Tractor, Inc., Olney, Texas, USA) operated at 217.3 km/h with a 3 m release height. In this test four drift control adjuvants were selected. Deposition, downwind drift, and droplet spectra characteristics over a cotton canopy were collected on water sensitive paper (WSP) and Mylar cards for measurement and analysis. In Stoneville, Mississippi, Huang and Thomson[16] tested CP-11TT flat fan nozzles on Air Tractor 402B as well with three nozzle spray flow rates, 9.5, 19 and 28.5 L/ha, three nozzle angles, 23°, 38° and 53°, and three release heights, 3.7, 4.9 and 6.1 m, to find out the best combination for optimal in-swath spray deposition. On the basis of this test, Huang and Thomson[17] further tested CP-11TT nozzles on Air Tractor 402B with a nozzle spray rate of 28.5 L/ha and 38° nozzle angle for three release heights, 3.7, 4.9 and 6.1 m, to assess in-swath spray deposition and drift downwind. The tests and evaluations provided useful information for understanding and application of the spray nozzles for practical crop protection. Similar test and evaluation of other nozzles are necessary to expand the understanding and application of various nozzles. Further, Thomson[18] conducted experiments within a soybean canopy to evaluate the Accu-Flo multiple orifice nozzle (Bishop Equipment Co., Hatfield, Pennsylvania, USA) for penetration of spray into a soybean canopy by comparing the results to those from a popular straight stream CP-09 nozzle (CP Products Co., Tempe, Arizona, USA) and Micronair rotary atomizer (Micron Group, Bromyard, Herefordshire, UK). In the experiments a mixture of water with an adjuvant was applied at three different spray release heights in a random sequence, also using Air Tractor 402-B. Spray sampling stations were set up at 24 in the field. WSP cards were clipped onto rigid stands just above the canopy and 30 cm off the ground within the canopy.

Development of new management practices is critical for increase in crop production worldwide. In corn production biological control is expected to combat aflatoxin, a poisonous by product produced by the fungi Aspergillus flavus and A. parasiticus, negatively impacts marketing and utilization of corn[19]. The non-toxigenic A. flavus has shown promise as a biological control agent for aflatoxin producing strains of the fungus[20,21]. Biological control efforts have focused on increasing non-toxigenic populations in soils to a level greater than toxigenic strains, thus preventing buildup of the harmful strain and release of its spores[22]. In corn production systems, many producers use Afla-Guard®[23,24], a commercially available product containing non-toxigenic A. flavus as a biological control agent. Crop consultants recommend applying it between the V10-V12 growth stages. To release the biological control agent into corn fields a suitable application technology is needed. For aerial application, there are obstacles that impede the adoption of Afla-Guard® and related products. First, the application of a coarse granule to mature, 2-meter-tall corn is a challenge. Aerial applicators are often in high demand and applicators are not commonly prepared at that time to handle granular materials, particularly at the low use rates labeled for Afla-Guard®. Thus, there would be substantial advantages to a liquid formulation. This would necessitate the identification of appropriate adjuvants to disperse the highly hydrophobic spores of A. flavus. Water dispersible granule (WDG) formulations have several advantages over wettable powder, emusifiable, oil or granular formulations. The development of WDG does not need solvents, and WDG formulations can greatly reduce the dust generated during application[25]. Moreover, WDG has less long-term residual impact on our environment than oil or emulsifiable formulations. The development of WDG formulations has been on the increase to be used for spray application. Jin et al.[26,27] applied the Hydrophilic-lipophilic Balance (HLB) number in the optimization of a compatible surfactant for hydrophobic aerial conidia of entomopathogenic fungi, and significantly improved the physical properties of formulations. Optimized compatible surfactants also improved the bio-herbicidal efficacy of Myrothecium verrucaria[28]. However, the suitable nozzles and spray settings are still issues to investigate, which need nozzle evaluation with the formulations to determine.

This paper describes the experiment design and discusses and preliminarily analyzes the results of our recent field test and evaluation of Davidon Tri-Set nozzles under various nozzle configurations, Further, a discussion is conducted for what we need to know for effective use of different nozzles for potential aerial application of biological control agents, especially Afla-Guard®, a commercially available product containing non-toxigenic A. flavus as a biological control agent, and related products.

2 Materials and methods

2.1 Nozzles

Among the nozzles used for aerial application, CP products are probably the most popular ones, including CP-03, CP-09 and CP-11TT, which are now owned by Transland (Wichita Falls, Texas, USA). The Davidon Tri-Set (Davidon, Inc., Unadilla, Georgia, USA) is a nozzle similar to the CP-03 but it was introduced after the CP product and has been picked up within the industry[29]. In 2016 Transland purchased and owned the Davidon dispersal products division from David Chancy who started Davidon, Inc. in 1992. The new ownership includes the Hi-Tek Rotary Atomizer, the Tri-Set Nozzle and Custom Boom systems. There is a current Tri-Set nozzle model. However, its measurement methods are not as well documented[29].

For this study, 60 Davidon Tri-Set nozzles were selected for 30 nozzles on each boom left and right of the aircraft and configured to deliver a total in swath application rate of averaged 48 L/ha at the pressure of 35 psi. These nozzles are 14 cm in apart between each of them. There are six CP nozzles in the middle of the booms but they were not switched on during the test. In settings the nozzles can be replaced with 3 selectable deflection planes of 0, 22.5 and 45 degrees and 3 selectable orifices of small, medium and large sizes for application rate of 23 L/ha, 36 L/ha and 84 L/ha respectively based on Davidon’s calibration of the nozzles.

2.2 Spray system

The field test was conducted using an Air Tractor 402B agricultural airplane (Air Tractor, Inc., Olney, Texas, USA) with a Satloc Airstar M3 guidance system (Hemisphere GPS, Calgary, BC, Canada). Global positioning, airplane heading, and real-time clock data were saved to flash memory during the spray runs. A Kestrel 4500 weather tracker (Nielsen-Kellerman, Boothwyn, Pennsylvania, USA) was configured alongside the test site to record wind speed, wind direction, air temperature, and relative humidity right before each flight pass.

2.3 Spray liquid

The sprayed liquid was water mixed with DRP-955 adjuvant (Davidon, Inc., Unadilla, Georgia, USA) at 7.8 mL/L.

2.4 Study layout

The field test was conducted on June 21-22, 2016 in a 5 ha Bermuda grass field. This field (33°26' 37″N, 90°53' 26″W and

37 m above mean sea level) was located near the irrigation research farm of the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) at Stoneville, Mississippi, USA. For evaluation of in-swath deposition of aerially applied materials WSPs were placed at each of seven sampling stations, +3, +2, +1, 0, –1, –2 and –3 (Figure 1). In the sampling line, from west to east, the seven sampling stations were evenly spaced 3.30 m apart across the swath. Effective swath width (corresponding to the distance within between stations +3 and –3) was set at 18 m.

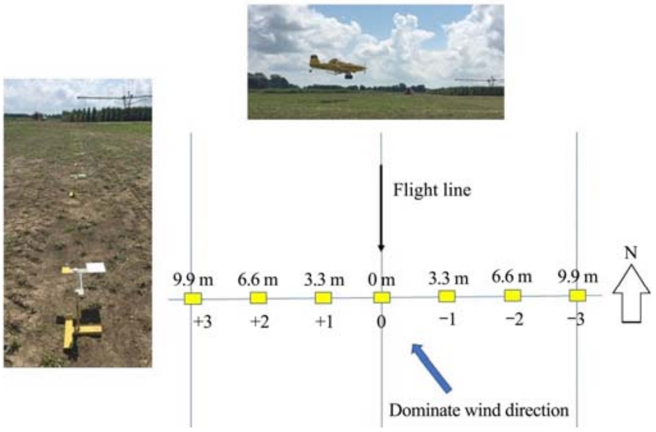


Figure 1 Test site layout

2.5 Field flights

The aircraft flew at 217 kph from north to south over the in-swath centerline basically into the wind. WSPs were collected after each flyover. The aircraft flew at 3.66 m of altitude to spray. The experiment was design and implemented to randomize the 36 flight runs (3 nozzle deflections x 3 nozzle orifices x 4 replications). So, for 7 sampling stations there were totally 252 WSP samples collected.

2.6 Sample and data processing

In the lab each WSP was scanned using a business-card scanner to generate a 600 DPI image into a software called DepositScan[30]. This software was designed to allow user-interact to generate parameters DV0.1, DV0.5, DV0.9, % Coverage, Image Area (cm), Deposits/cm², and Deposition (µL/cm^2). DV0.1, DV0.5, and DV0.9 are important parameters to describe spray droplet size spectra. DV0.5 is the droplet diameter where 50% of the spray volume or mass is contained in droplets smaller than this value. DV0.5 is also referred as Volume Median Diameter (VMD). After WSP sample scanning and data processing in DepositScan 252 rows of the parameter data were generated and averaged for all four replications for each record for further processing and preliminary analysis.

3 Results

Weather data were recorded (Table 1). Weather data were obtained from the stationary Kestrel 4500 weather tracker system placed in the field at the time of the test. The flight direction was straightly from north to south. The wind direction varied with an 18-degree standard deviation, having an average value of 328 degrees from the True North. The varied wind directions are typical in field. It is noted that this was a two-day test and the first-day test was conducted from beginning until "22.5 degree, large size orifice, rep 2" and the rest of the fights were conducted in the second day, where the weather change on the second day can be seen. Basically, during the test periods of the two days, the temperature increased, and the humidity decreased with time, but the wind speed was kind of uncertain.

Table 1 Weather data recording during the field test

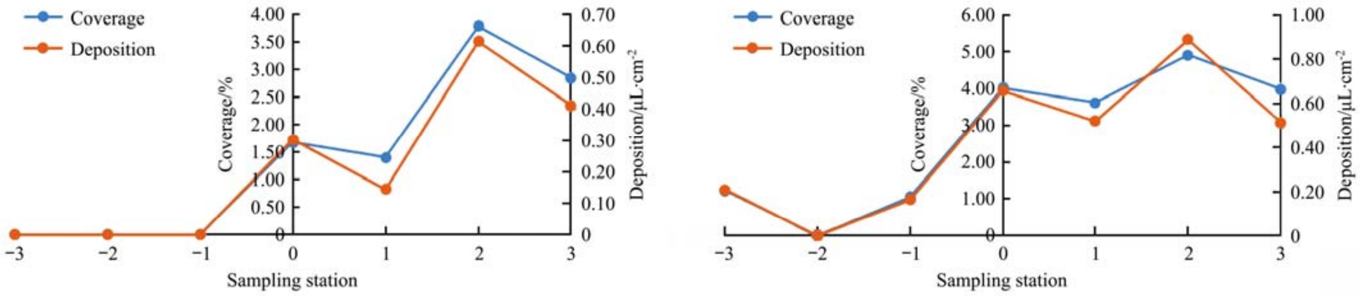
Nozzle Setting	Temperature /°C	Humidity /%	Wind speed /mps
0 degree, small size orifice, rep 1	30.6	66.5	2.0
0 degree, small size orifice, rep 2	30.7	64.2	2.0
0 degree, small size orifice, rep 3	30.1	62.5	2.6
0 degree, small size orifice, rep 4	31.0	65.7	1.5
0 degree, medium size orifice, rep 1	31.5	60.1	1.5
0 degree, medium size orifice, rep 2	30.7	61.0	1.0
0 degree, medium size orifice, rep 3	30.6	61.8	2.7
0 degree, medium size orifice, rep 4	32.5	62.0	1.8
0 degree, large size orifice, rep 1	32.5	55.6	1.2
0 degree, large size orifice, rep 2	31.4	58.8	3.0
0 degree, large size orifice, rep 3	31.1	59.0	1.2
0 degree, large size orifice, rep 4	31.3	60.0	1.9
22.5 degree, small size orifice, rep 1	32.1	58.6	1.9
22.5 degree, small size orifice, rep 2	31.6	59.1	2.2
22.5 degree, small size orifice, rep 3	31.9	56.4	2.2
22.5 degree, small size orifice, rep 4	32.4	57.2	2.2
22.5 degree, medium size orifice, rep 1	31.9	56.1	1.9
22.5 degree, medium size orifice, rep 2	31.9	57.6	1.3
22.5 degree, medium size orifice, rep 3	31.4	56.2	2.6
22.5 degree, medium size orifice, rep 4	31.5	57.6	1.7
22.5 degree, large size orifice, rep 1	33.6	56.1	0.8
22.5 degree, large size orifice, rep 2	33.4	56.9	0.4
22.5 degree, large size orifice, rep 3	30.9	72.9	2.4
22.5 degree, large size orifice, rep 4	29.4	73.8	1.6
45 degree, small size orifice, rep 1	29.8	72.6	2.0
45 degree, small size orifice, rep 2	29.7	71.3	3.0
45 degree, small size orifice, rep 3	32.3	71.8	1.9
45 degree, medium size orifice, rep 4	30.6	70.7	3.1
45 degree, small size orifice, rep 1	30.3	70.3	2.9
45 degree, medium size orifice, rep 2	30.6	67.9	3.8
45 degree, medium size orifice, rep 3	31.8	70.0	1.9
45 degree, medium size orifice, rep 4	30.9	67.7	3.2
45 degree, large size orifice, rep 1	31.0	67.5	3.5
45 degree, large size orifice, rep 2	31.3	64.3	2.5
45 degree, large size orifice, rep 3	31.1	64.5	2.9
45 degree, large size orifice, rep 4	31.8	65.2	2.6

Figures 2, 3 and 4 show the distributions of percent coverage and deposition on WSPs over the sampling stations for 0 degree, 22.5 degree and 45 degree nozzle deflections, respectively, with small, medium and large orifices. These figures consistently show the spray profiles with the plane turbulence and wind, especially 22.5 degree deflection with large orifice.

Figures 5, 6 and 7 further show the droplet distribution over the sampling stations for 0 degree, 22.5 degree and 45 degree nozzle deflections, respectively, with small, medium and large orifices. Besides DV0.1, DV0.5 and DV0.9 droplets, corresponding relative spans are calculated and plotted:

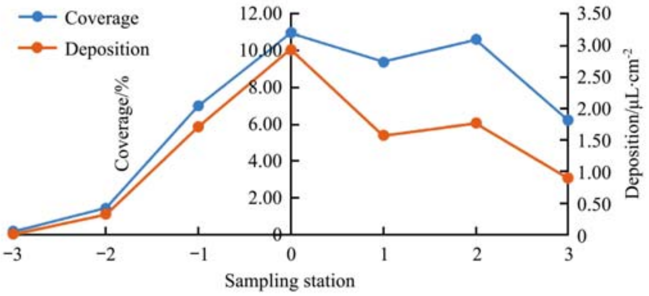
$$RS = \frac{DV0.5}{DV0.9 - DV0.1}$$

The relative span (RS) is used to explain that the smaller this number, the less variation there is between the size of the droplets in the spray spectrum. The figures indicate that for 0 degree deflection for small and medium orfices the smaller the droplets, the less variation while for large orfice it is uncertain; the stiuation of 22.5 degree is similar for small and medium orfices but for large orfice seems a pattern existing for less variation with increasing distance away from the flight central line; and for 45 degree deflection is also like that the smaller droplets, the less variation but for large ofice is uncertain.



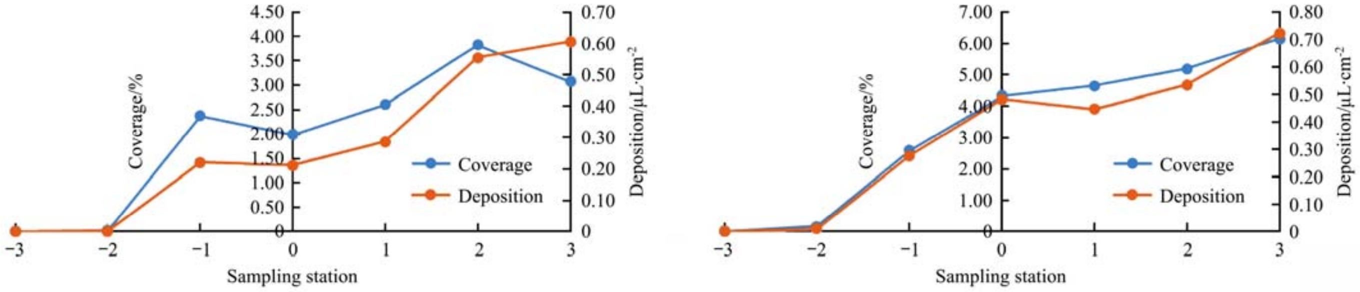
a. 0 degree, small orifice

b. 0 degree, medium orifice



c. 0 degree, large orifice

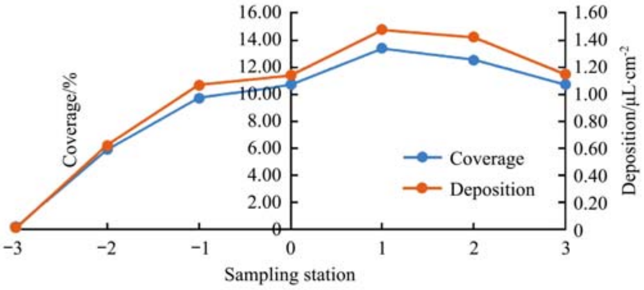
Figure 2 Percent coverage and deposition of 0 degree nozzle deflection with small, medium and large orifices



a. 22.5 degree, small orifice

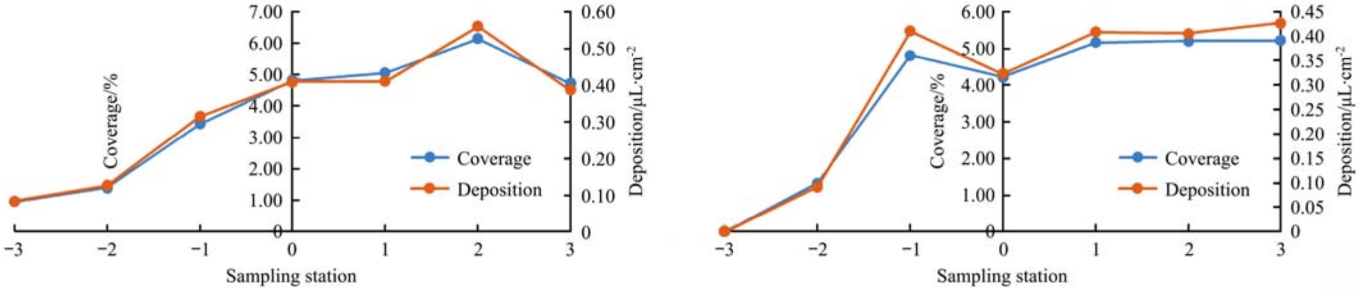
b. 22.5 degree, medium orifice

a. 0 degree, small orifice b. 0 degree, medium orifice



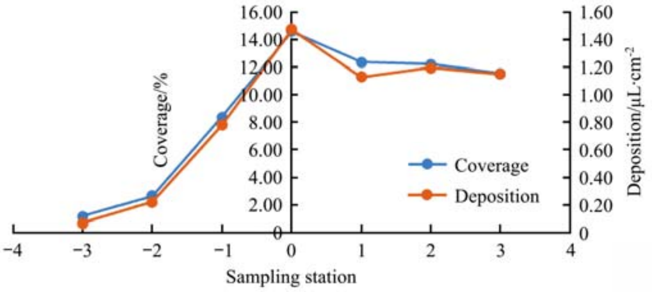
c. 22.5 degree, large orifice

Figure 3 Percent coverage and deposition of 22.5 degree nozzle deflection with small, medium and large orifices



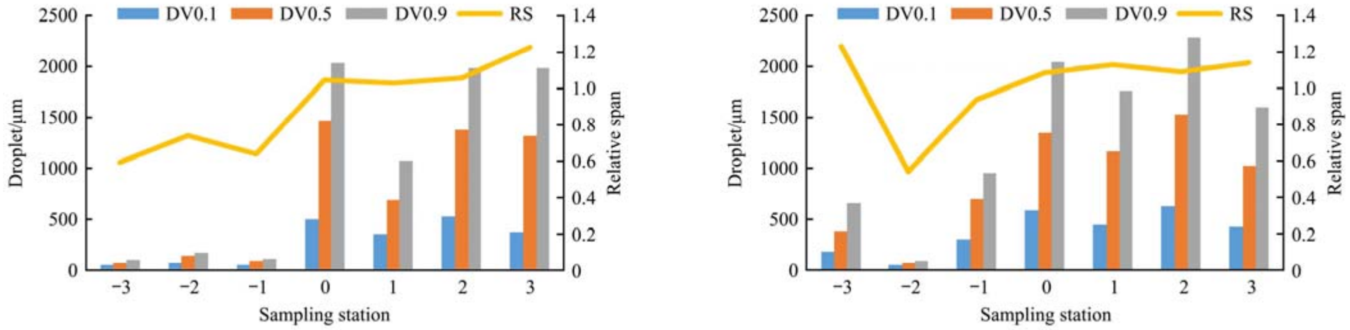
a. 45 degree, small orifice

b. 45 degree, medium orifice



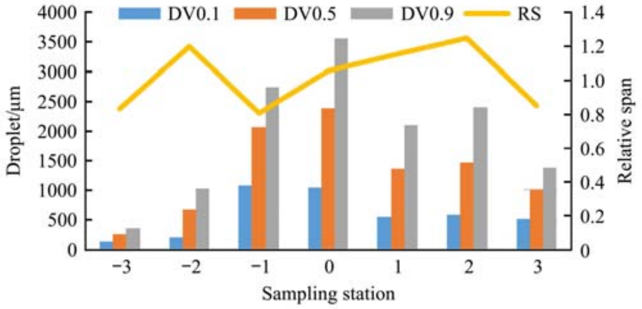
c. 45 degree, large orifice

Figure 4 Percent coverage and deposition of 45 degree nozzle deflection with small, medium and large orifices



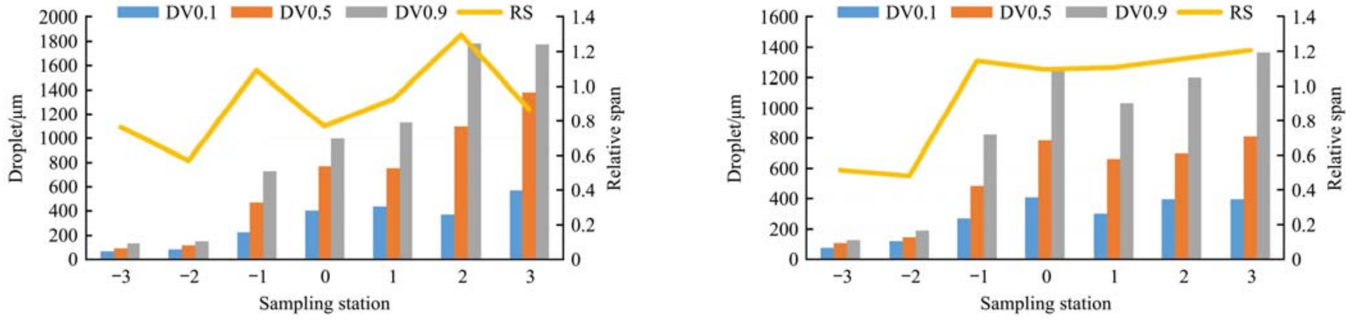
a. 0 degree, small orifice

b. 0 degree, medium orifice



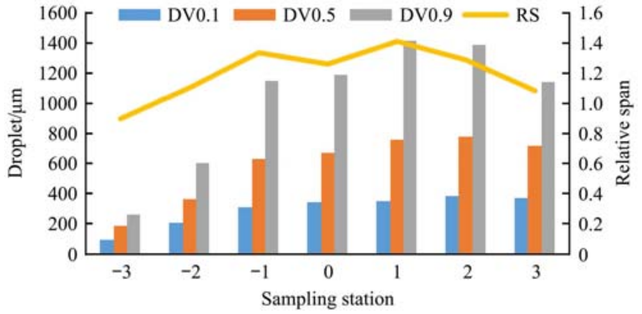
c. 0 degree, large orifice

Figure 5 Droplet spectra of 0 degree nozzle deflection with small, medium and large orifices



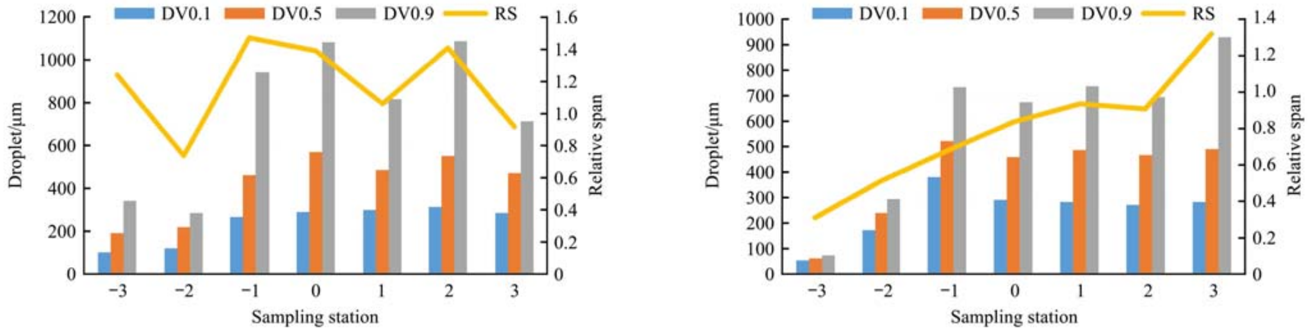
a. 0 degree, small orifice

b. 0 degree, medium orifice

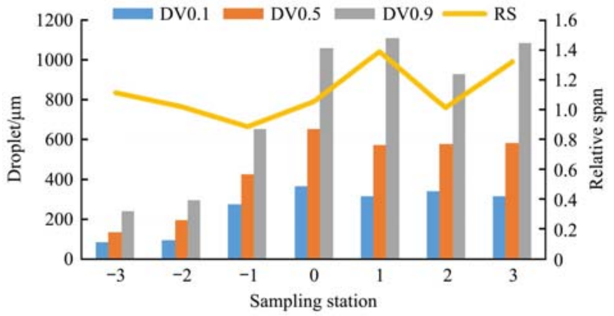


c. 0 degree, large orifice

Figure 6 Droplet spectra of 22.5 degree nozzle deflection with small, medium and large orifices



a. 0 degree, small orifice
b. 0 degree, medium orifice



c. 0 degree, large orifice

Figure 7 Droplet spectra of 45 degree nozzle deflection with small, medium and large orifices

Figure 8 shows the distribution of the coefficient of variation (CV) over DV0.1, DV0.5 and DV0.9 with the combinations of 3 nozzle deflections × 3 nozzle orifices. Richardson et al.[31] investigated calibration of aerial fertilizer equipment as typically undertaken by releasing material from over collectors that are aligned perpendicularly to the aircraft travel path. The amount of material deposited in each collector defines the shape of the swath pattern. Computer software can then be used to overlap the swath pattern with itself, the distance between overlaps being the input lane separation (distance between flight lines). The deposition profile across the spray block is calculated by summing overlapped deposit values. The mean of these values represents the pesticide application rate and the uniformity of the application (or variability) can be calculated as the CV which is defined as:

$$CV(\%)=\frac{Standard\ Deviationin\ Deposition\times 100}{Mean\ Deposition}$$

With the concept of CV, from Figure 8, it found that with the three droplets 22.5 degree deflection with large orifice and 45 degree deflection with small orifice have the better spray uniformity than other settings (red circled bars in the figure).

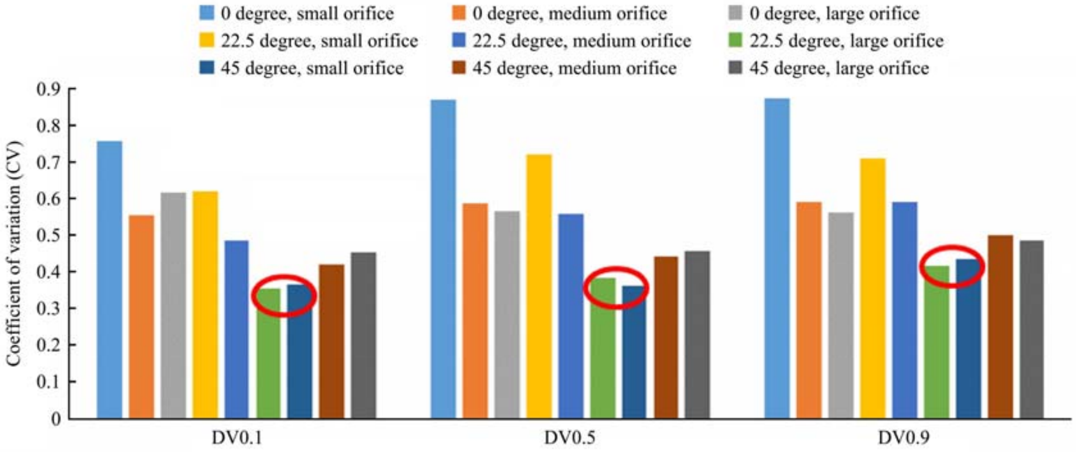


Figure 8 CV distribution of nozzle deflection/orifice combinations over droplets

Overall, considering what indicated by percent coverage, deposition, droplet spectra and CV, the setting of 22.5 degree deflection and large orifice for the Davidon Tri-Set nozzles is recommended from the experiment of this study for best performance in general.

4 Discussion

The droplet spectra of the Davidon Tri-Set nozzles are quite coarse in general in terms of the ASABE Droplet Classification Standard[32]. However, the issue is still under investigation to determine if the nozzles can be directly used to aerially spray WDG formulations of biological agents. As briefly mentioned above, Aflatoxin is a poisonous by product produced by the fungi Aspergillus flavus and A. parasiticus, which has negatively impacts on marketing and utilization of corn. Release of non-toxigenic A. flavus into corn fields has shown promise as a biological control agent for aflatoxin producing strains of the fungus. In corn production systems, many producers use Afla-Guard® (Syngenta Crop Protection, LLC, Greensboro, North Carolina, USA), a commercially available product containing non-toxigenic A. flavus as a biological control agent with crop consultants' recommendations should be applied into corn fields between the V10-V12 growth stages. For aerial application, there are obstacles that impede the adoption of Afla-Guard® and related products. The application of a coarse granule to mature, two-meter-tall corn is a challenge. Aerial applicators are often in high demand and applicators are not commonly prepared at that time to handle granular materials, particularly at the low use rates labeled for Afla-Guard®. Thus, there would be substantial advantages to a liquid formulation. WDG formulations have several advantages over wettable powder, emusifiable, oil or granular formulations. The development of WDG does not need solvents, and WDG formulations can greatly reduce the dust generated during application. Moreover, WDG has less long-term residual impact on our environment than oil or emulsifiable formulations. Jin et al.[26, 27] enhanced the development of WDG formulations. Application efficiency and efficacy from aerial platforms have been studied extensively as described above. However, more information is needed on the ability of aerial delivery systems to effectively apply biological agents, especially new specialized mixtures such as those described by Jin et al.[33, 34]. One nozzle that could be further considered for this application is the Accu-Flo nozzle. This nozzle finds extensive use in Forestry applications and was found to penetrate spray most effectively into soybean canopies[35]. As mentioned above it has been evaluated for canopy penetration[18]. This nozzle is unique in that it does not use pressure to shatter the spray into small droplets, and this non-shattering characteristic might also have significant advantages when applying relatively delicate biological products

5 Conclusions

From the preliminary data analysis from the field test, it found that the droplet spectra of Davidon Tri-Set nozzles are quite coarse in terms of ASABE droplet size classification standard, and considering what indicated by percent coverage, deposition, droplet spectra and CV, the setting of 22.5 degree deflection and large orifice for the Davidon Tri-Set nozzles is preferred for best performance for general use of aerial application for drift reduction in crop protection. However, it is still a question to investigate if the nozzles can be directly used to aerially spray WDG formulations of biological agents. Other nozzles, such as Accu-Flo nozzle, are recommended to test.

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