Characterization of spray deposition and drift from a low drift nozzle for aerial application at different application altitudes

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Abstract: A complex interaction of controllable and uncontrollable factors is involved in aerial application of crop production and protection materials. Although it is difficult to completely characterize spray deposition and drift, these important factors can be estimated with appropriate sampling protocol and analysis. Application height is an important variable influencing off-target spray drift, but this variable has not been easily measured or logged. A custom-configured aircraft-mounted laser with logging capabilities makes this possible. This study was designed to investigate droplet size and deposition characteristics of a low drift CP flat-fan nozzle at application altitudes 3.7 m, 4.9 m, and 6.1 m. In the study, CP flat-fan nozzles were set to a downward angle of 30 degrees applying a mixture of water, Syl-Tac® adjuvant, and Rubidium Chloride (RbCl) tracer at a 28.5 L/ha application rate. Spray droplets were collected using water sensitive paper (WSP) cards placed in the spray swath. Mylar sheets were also placed in the swath and downwind for drift sampling. Statistical analysis indicated that median droplet diameter as determined by WSP in the spray swath was not significantly influenced by spray application height. Similarly, statistical analysis also indicated that concentration of RbCl tracer from Mylar samplers in the spray swath was not significantly influenced by application height. Application height had a significant effect on spray deposition from drift samplers, along with wind direction and relative humidity. Final results for drift samplers may have been influenced by shifts in wind direction that altered the relationship between orientation of samplers and wind.

Keywords: deposition, spray nozzle, aerial application, droplet spectra, spray drift

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1 Introduction

It is important for aerial application of pesticide to be cost-effective and environmentally protective. Reduction of off-target spray drift from aerial application of pesticide is possible with careful attention to the aircraft spray setup. Proper set up for spray operation, including spray nozzle selection and spray operation configuration, is vital for agricultural application[1]. Variations in application rate, spray application height, nozzle angle and deflection relative to airstream, airplane speed, and spray pressure are commonly considered. Complex interactions of these factors with weather make complete characterization of spray drift difficult to understand[2], and these factors can significantly influence on- and off-target deposition and the overall effect of the operation of pesticide application[3-4].

Studies have indicated that application droplet size and spray mixture significantly affect the performance of aerial applications[5-9]. Height of spray application can also have a significant influence on in-swath and downwind spray deposition, but accurate and convenient recording of spray application height has not yet been implemented for use in spray drift studies.

The interaction between application rates and nozzle angle with weather conditions has been studied for a selected flat-fan nozzle[10]. The study described herein sets application rate and nozzle angle to consider the

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effect of application height on in-swath and downwind spray deposition. An on-board laser with data logging capabilities was used to record spray release height.

The objective of this study was to evaluate the effect of application height on in-swath and downwind spray deposition and droplet spectra.

2 Materials and methods

2.1 Nozzle

For this study, thirty-one CP-11TT nozzles bodies (CP Products, Inc., Tempe, Arizona fitted with a 4020 nozzle tip (40 degree flat fan with a #20 orifice) were selected and configured to deliver a total in swath application rate of 28.5 L/ha. The nozzles were operated at a spray pressure of 30 psi. CP-06 swivels were used to adjust the nozzle angle to a fixed downward angle of 30 degrees[10]. The CP11TT nozzle bodies are configured such that a nozzle, when orientated parallel to the airstream (0 degree deflection), is angled into the airstream at a slight 8 degree angle, which means that with the swivel set at 30 degree deflection, the total deflection angle is 38 degrees.

2.2 Spray system

The field test was conducted using an Air Tractor 402B agricultural airplane (Air Tractor, Inc., Olney, Texas) 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 laser height sensor, Universal Laser Sensor (ULS) (Laser Technology, Inc, Centennial, CO), was mounted on the aircraft to measure actual heights of spray release. A Kestrel 4500 weather tracker (Nielsen-Kellerman, Boothwyn, PA) was configured alongside the test site to record wind speed, wind direction, air temperature, and relative humidity every two seconds. An instrumented weather station with a Campbell CR-21X micrologger was used as backup and for comparison with weather data from the Kestrel unit. Time clocks from the Kestrel unit, notebook PC reading the laser, and the Campbell CR-21X were all synchronized to atomic time.

2.3 Spray liquid

The sprayed liquid was water mixed with Syl-Tac® adjuvant (Wilbur-Ellis Company, San Francisco, CA) at 1.4 oz/gal and 2.6 g Rubidium Chloride (RbCl) tracer in the tank mix to allow relative indications of in-swath and downwind proportional concentrations of sprayed liquid to be estimated.

2.4 Study layout and field testing

The field test was conducted on June 30, 2009 in a 6.7 ha Bermuda grass field. This field (33°26 28″N, 90°53 16″ W and 37 m above mean sea level) was located near the research station of the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) at Stoneville, Mississippi, USA. In-swath deposition of applied material released from the aircraft was measured using WSP and Mylar sheets placed at stations 1 to 7 (Figure 1). In the sampling line, from northwest to southeast, stations 1 to 7 were evenly spaced 4.57 m apart across the swath. Effective swath width (corresponding to the distance between stations 2 and 6) was set at 18.29 m. For drift sampling, Mylar sampling sheets were placed at stations 8, 9, 10, and 11 at 10.67 m, 17.78 m, 25.3 m, and 39.62 m distances from station 7, respectively (Figure 1).

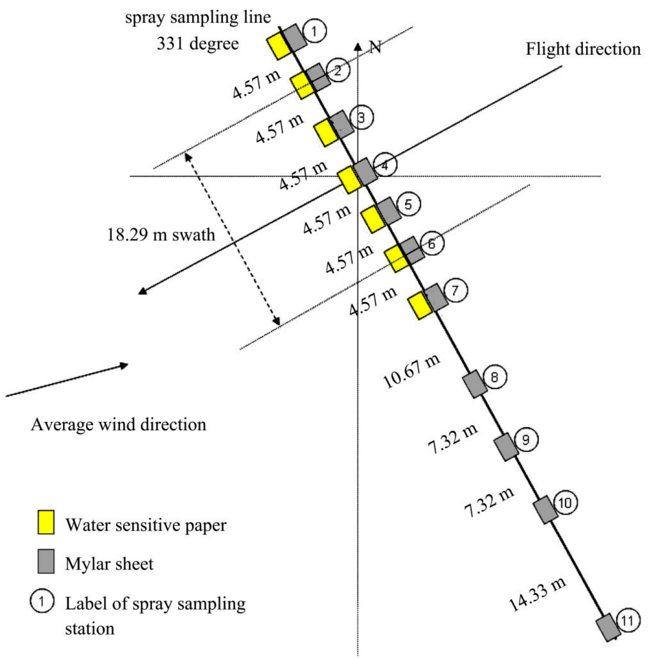

Figure 1 Field test site layout

The aircraft flew from northeast to southwest over the in-swath centerline. WSP and Mylar sheets were collected after each run. The aircraft flew three passes at each of three different altitudes, 3.7 m, 4.9 m, and 6.1 m. The three altitude “groups” were replicated three times in random order within each replication. The initial plan was to randomize the 27 flight runs (3 altitudes×3 passes×3 replications); during the second replication, operations were terminated due to lack of spray material in the tank. Therefore, the first replication for all three altitudes and a partial second replication with two altitudes (3.7 m and 4.9 m) were conducted; the remaining altitudes and replications were not run. The collected data were from 15 flight runs (3 altitudes×3 passes + 2 altitudes×3 passes), which resulted in 105 collected WSP cards (15 runs×7 stations in-swath) and 165 Mylar sheets (15 runs×11 stations in-swath and downwind).

2.5 Sample and data processing

In the lab each WSP was scanned using a camera-based imaging system and SigmaScan 5.0 (Systat Software, Inc., San Jose, CA) to generate droplet parameters from each of the cards, including total and percentage card area covered by spray droplets, diameter of each droplet, droplet "compactness," and total number of droplets on cards. Compactness is a measure of droplet "roundness" or the perimeter^2 /area.

After processing by spreadsheet macros to sort droplet data and determine cumulative droplet areas for calculation of size parameters[11], the data were fed into a Matlab (The MathWorks, Inc., Natick, MA) program for further processing. The program was designed to allow screening of droplets below a user-selected compactness threshold and generate parameters $D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$ before accounting for spread factor. Compactness in this case was set to a value of 22, with 12.57 being a perfectly round droplet. The spread factor equation chosen was the USDA version as used previously by Thomson at al.[11] and described by Hoffmann and Hewitt[12]. $D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$ are important parameters to describe spray droplet size spectra. $D_{V0.5}$ is the droplet diameter (μm) where 50% of the spray volume or mass is contained in droplets smaller than this value. $D_{V0.5}$ is also referred as Volume Median Diameter (VMD).

In the lab, each Mylar sheet was shaken on a shaker for 20 min (10 min on each side) to ensure complete washing of the sheet. The rinse solution was a 1% HNO_3 (nitric acid) solution, which is also used for the calibration blank on the AAnalyst 600 Atomic Absorption Spectrometer (PerkinElmer, Waltham, MA). The AAnalyst 600 spectrometer was used to determine the concentration of RbCl tracer on each sheet in the units of μg/L.

2.6 Statistical analysis

All data were analyzed using a mixed effects model for SAS 9.13 (SAS Institute, Inc., Cary, NC). Operational parameters were application height with wind speed, wind direction, air temperature, and relative humidity.

3 Results and discussion

Application heights and 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 from northeast to southwest at 61 degrees to the north. The wind direction varied with a 24 degree standard deviation, having an average value of 256 degrees from True North. The varied wind directions are typical in field. The effect of the averaged provides a scenario for practical analysis.

Table 1 Application height and weather data for CP nozzle test

Run	Actual application height/m	Wind direction (Degrees from true north)	Wind speed /m·s^{-1}	Temperature /℃	Relative humidity/%
1	3.34	292	2.5	32.8	50.7
2	3.37	318	2.7	32.2	50.4
3	3.29	250	2.9	32.6	51.7
4	4.95	254	3.2	32.3	50.7
5	4.45	265	2.1	32.8	48.7
6	4.94	254	2.9	33	54.1
7	5.75	248	2.1	33.6	48.1
8	5.57	277	1.4	32.1	55.3
9	5.33	226	1.1	32.9	54.1
10	4.81	218	2.2	33.2	50.4
11	5.08	253	2	33.8	50.1
12	5.15	247	1.7	33.9	52.2
13	4.57	257	3.4	33.4	46.3
14	3.58	249	1.9	32.8	45.5
15	3.48	231	3.3	33.2	46.4

The SAS mixed effects model was implemented using PROC Mixed to analyze the data for evaluating the in-swath and drift effects of application height using CP flat-fan nozzles.

In-swath (sampling stations 2 to 6) results were obtained starting with sampling station, application height, sampling station*application height, wind direction, wind direction, temperature, and relative humidity as independent variables. Non-significant effects and interaction terms were progressively dropped out.

Sampling station location and wind direction showed significant effects on RbCl concentration at the 1% level of significance (p=0.0004 and 0.0016 respectively), but application height was not a significant factor. Examination of raw data indicated the effect, which might be caused by the varied wind direction (Figure 2). Sampling station location and wind direction showed significant effects on VMD (p<0.0001 and =0.0003, respectively) but again, application height was not a significant factor. The interaction of sampling station and application height was a significant effect on the percentage card area covered (p<0.0001), but application height by itself was not significant. It is interesting to note that this interaction was significant for droplet density using spray cards but not RbCl concentration sampled from Mylar.

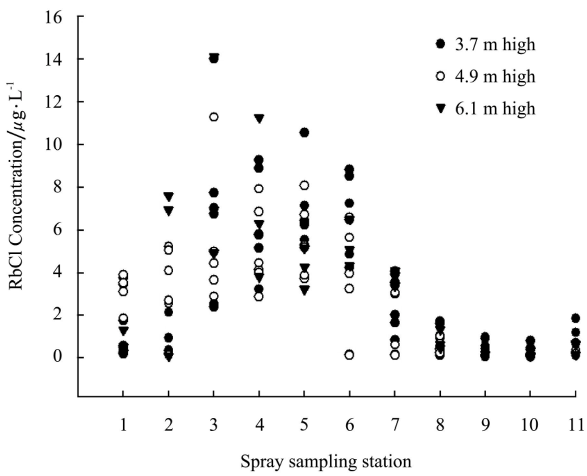

Figure 2 Concentration of RbCl on Mylar as a function of all spray sampling station locations pooled across all other variables

Statistical results were then obtained for sampling stations 7 to 11. Results indicate that the effect of application height was not significant on RbCl concentration while the interaction term sampling station*application height and wind direction were significant effects on drift as determined by RbCl concentration from Mylar samplers placed downwind (p<0.0001 for both effects). This indicates that there was an application height effect, but this effect depended upon the location of the downwind station. Examination of raw data revealed a very high variability in RbCl concentration pooled across all runs for station 7 (Figure 3).

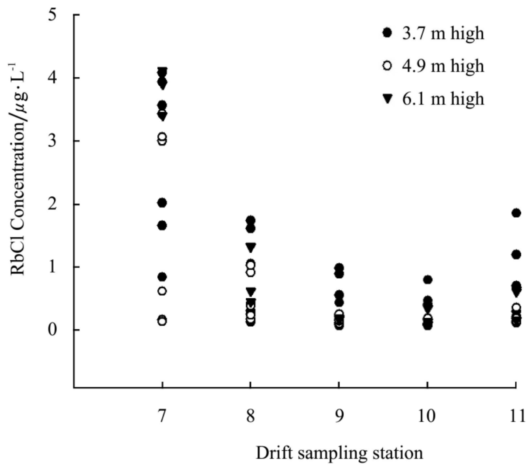

Figure 3 Concentration of RbCl on Mylar as a function of drift sampling station location pooled across all other variables

Station 7 is close to the edge of the spray swath, and standard deviation of average RbCl concentration for station 7 was 1.48 μg/L, almost three times higher than the next highest value (std. dev. at station 8 = 0.53 μg/L). If station 7 is taken out of the data set and only samplers 8 through 11 are used, spray application height has a significant effect on drift (p = 0.0034) as determined by concentration of RbCl on Mylar sampling sheets. Spray application height did not interact with sampling location when Station 7 was taken out, and a more expected result also indicated significant effect of station location at the 1% level of significance (p=0.0003). Relative humidity and wind direction were also significant at the 1% level (p=0.0040 and <0.0001 respectively).

4 Summary and conclusions

The purpose of this research was to evaluate the effect of application height on in-swath and downwind spray deposition and droplet spectrum from fixed wing aerial application using flat-fan CP-11 TT spray nozzles. For the limited data set obtained, results indicated that application height, across the limited application heights tested, did not have a significant effect on in-swath spray deposition but had significant effect on spray deposition as recorded from drift samplers. Wind direction progressed in a fashion that was almost perpendicular to the spray sampling line by the end of the day. These were good conditions for the in-swath portion of the study but potentially problematic for the drift component of the study. Even so, the overall trend of drift as obtained as RbCl concentration on Mylar samplers showed an expected pattern (decreasing concentration with increasing distance from the spray swath). When station 7 in close proximity to the swath was removed from the data set for drift analysis, statistical results indicated a distinct effect of application height on downwind drift as determined as RbCl concentration from Mylar samplers.

Only statistical significance of application variables that include spray application height has been reported on herein. More detail regarding the magnitude of these effects on downwind spray deposition will be reported on subsequently, and aircraft loading will be adjusted to assure more replications can be studied. Experiments will assure a consistent wind direction favorable for obtaining additional spray deposition data downwind.

Based on the results of this study, the following were observed:

1) For in-swath samplers, statistical analysis indicated that application height did not have a significant effect on percent spray coverage, VMD, or RbCl concentration.

2) The interaction of sampling station location and application height was a significant effect on spray deposition as determined by percent spray coverage obtained from WSP, which could be caused by the varied wind direction during the test.

3) Statistical analysis indicated that application height interacted with wind direction had a significant effect on the spray percentage card area coverage as recorded by relative concentration of RbCl on drift samplers.

4) Wind direction was a significant effect for all analyses except for in-swath percent spray coverage. Differences in relative humidity significantly affected concentration of RbCl obtained from Mylar drift samplers placed downwind.

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Disclaimer

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