Characterizing downwind drift deposition of aerially applied glyphosate using RbCl as tracer

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Abstract: Rubidium chloride (RbCl) was used as a tracer tank-mixed with active ingredients to profile downwind deposition of aerially applied crop protection and production materials to characterize off-target drift, which helps improve spray efficiency and reduce environmental contamination. Mylar sheets were placed on a holder in the field at each sampling station to collect sprayed solution. RbCl tracer was used to assess downwind drift of nozzles mounted on the booms installed and controlled on both sides of an agricultural airplane. The experiment was conducted on a field covered by Bermuda grass (*Cynodon dactylon*). During the experiment, the airplane was planned to fly three passes with three replications at each of three different altitudes, 3.7 m, 4.9 m, and 6.1 m for total of 27 flight runs. The results indicated that sampling station location had a significant effect on RbCl concentration. However, application release altitude was not significant to the change of RbCl. Another practical application in the same aerial application system was used to assess crop injury from the off-target drift of aerially applied glyphosate. RbCl concentrations measured from Mylar sheets were correlated with visual injury, plant height, shoot dry weight, leaf chlorophyll content, and shikimate, which were measured from the leaves and plant samples collected. Overall, RbCl is an effective tracer for monitoring spray applications from agricultural aircraft and unmanned aerial vehicles to intensify agriculture output and minimize environmental impact.

Keywords: Rubidium chloride (RbCl), precision agriculture, spray efficiency, off-target drift, aerial application, herbicide, crop injury, environmental pollution

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1 Introduction

The primary concern of aerial applicators and farm producers with aerial application of crop protection and production materials is that they be cost-effective and efficient with application, consistent with environmental safety. Precision agriculture aims to input irrigation, fertilizer and pesticide in the correct dose, locations and time[1-3] allowing sustainable intensification[4]. Thus, targeted application in a precise manner has benefits for reducing overall spray amounts with a commensurate reduction in off-target drift. Significant reduction in off-target spray drift from aerial application is further

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achieved with proper aircraft spray setup, including spray nozzle selection and spray operation configuration in application rates, spray application height, nozzle angle and deflection relative to airstream, airplane speed, and spray pressure[5,6]. The interactions of these controllable factors with varied weather conditions make complete characterization of spray drift difficult[5,7]. In order to characterize off-target drift, an effective method is needed to profile downwind deposition of aerially applied chemicals. There are two popular methods that can be used to determine ground deposition of the spray liquid. One method is to use water-sensitive paper (WSP) cards to quantify spray droplet spectra[8]. Another method is to mix tracer materials, such as oil and water-soluble fluorescent dyes into spray solutions in small amounts with minimal impact on the solution physical properties and atomization characteristics of the spray nozzle system[9]. Typically, WSP cards are used for determining spray in-swath deposition and a transducer with variable dielectric capacitor was developed to quantify in-swath deposition similarly[10] while the tracer is more used to assess the off-target drift of aerially applied chemicals[11,12]. 1,3,6,8-pyrene tetra sulfonic acid tetra sodium salt (PTSA) was evaluated as a spray tracer dye[13]. This study introduces a method that mixes small amount of oil and water-soluble Rubidium Chloride (RbCl) (99% metal purity), known to be biologically inert[14], into the spray solutions as tracer to indicate the concentration of downwind proportional deposition of aerially applied solutions to effectively characterize off-target drift. Use of metal salts such as RbCl is consistent with several studies that showed improved results over use of fluorescent dyes as tracer[15]. The objective of the research is to evaluate the RbCl tracer method for profiling downwind depositions of aerially applied solutions from agricultural aircraft or unmanned aerial vehicles, to characterize off-target drift. As more information dissemination is needed in precision agriculture[16], this paper further reports two applications of a RbCl tracer method for a low-drift nozzle evaluation and crop injury assessment from the off-target drift of aerially applied glyphosate.

2 Materials and methods

2.1 Mylar sheets and RbCl quantification

To quantify RbCl tracer contained in the spray tank for aerial applications, Mylar sheets were used as samplers. As Figure 1 shows, each Mylar sheet was placed on a holder in the field at a sampling station. The Mylar sheet is polyester based film with a matte translucent drawing surface on one side and has an area of 130 mm × 127 mm. Mylar sheets from all sampling stations were collected after each spray run and transported to the laboratory. In the laboratory, 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 was also used for the calibration blank on an AAnalyst 600 Atomic Absorption Spectrometer (PerkinElmer, Waltham, MA). This spectrometer was used to determine the concentration of RbCl tracer on each sheet in unit of μg/L. The AAnalyst 600 is equipped with a transversely heated THGA graphite furnace Atomic Absorption with longitudinal Zeeman-effect background correction and has a practical quantitation limit (PQL) of 0.7 ppb. The spectrometer and furnace are controlled using WinLab 32 software.

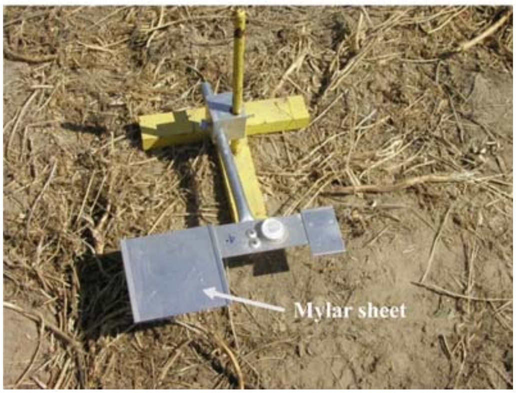


Figure 1 Mylar sheet on the holder in the field

Prior to experiments, a Mylar recovery test was first performed. Ten drops of a 500 μL spiked solution of RbCl was applied to ten Mylar sheets, replicated twice. The solution was allowed to evaporate, and the sheets were then rinsed with 1% HNO_3 before analysis on the atomic absorption spectrometer. The mean concentration of RbCl recovered was 26.37 μg/L as compared with 28.68 μg/L spiked solution; an estimated recovery of 92%.

2.2 Booms and nozzle setups

RbCl tracer has been used to assess downwind drift of CP-11TT nozzles (CP Products, Inc., Wichita Falls, Texas, USA). For this assessment, thirty-one CP-11TT nozzle bodies fitted with a 4020 nozzle tip (40º flat fan with a #20 orifice) were mounted on the booms installed and controlled on both sides of an Air Tractor 402B agricultural airplane (Air Tractor Inc, Olney, Texas, USA) (Figure 2). Agricultural aircraft remains an advantage over unmanned aerial vehicle (UAV) for this application, because they are directed by a pilot and can travel longer distances[17]. The spray booms were configured to deliver an in-swath application rate of 28.5 L/hm^2. The nozzles were operated at a spray pressure of 30 psi (1 atm = 14.696 psi). CP-06 swivels were used to adjust the nozzle angle to a fixed downward angle of 30º based on our previous study[11].

Figure 2 Air Tractor 402B with CP-11TT nozzle booms

3 Results and discussion

3.1 RbCl tracer for low-drift nozzle evaluation

The experiment was conducted on a field covered by Bermuda grass (*Cynodon dactylon*), a salt-tolerant forage for livestock having lignocellulose with a low lignin content able to biodegrade chemicals[18-20]. The field has an area of 6.7 hm^2 (33°26'N, 90°53'W) on the research farm of the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) at Stoneville, Mississippi, USA. In-swath deposition of applied materials released from the airplane was measured using WSP cards and Mylar sheets placed at Stations 1 to 7 (Figure 3). 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 downwind drift sampling, Mylar sampling sheets were also placed at stations 8, 9, 10, and 11 at 24.38 m, 31.7 m, 39.02 m, and 53.35 m distances from station 7, respectively (Figure 3).

The sprayed liquid was water mixed with Syl-Tac® adjuvant (Wilbur-Ellis Company, San Francisco, California, USA) at 1.4 oz/gal (1 oz = 29.27 ml, 1 gal = 3.785 L) and 2.6 g RbCl tracer in the tank mix to allow relative indications of in-swaths and downwind proportional concentrations of sprayed liquid to be estimated.

In the experiment the average temperature is 32.2^{o}C, average humidity 50.4%, average wind speed 2.1 m/s and average wind direction 248º from the true north.

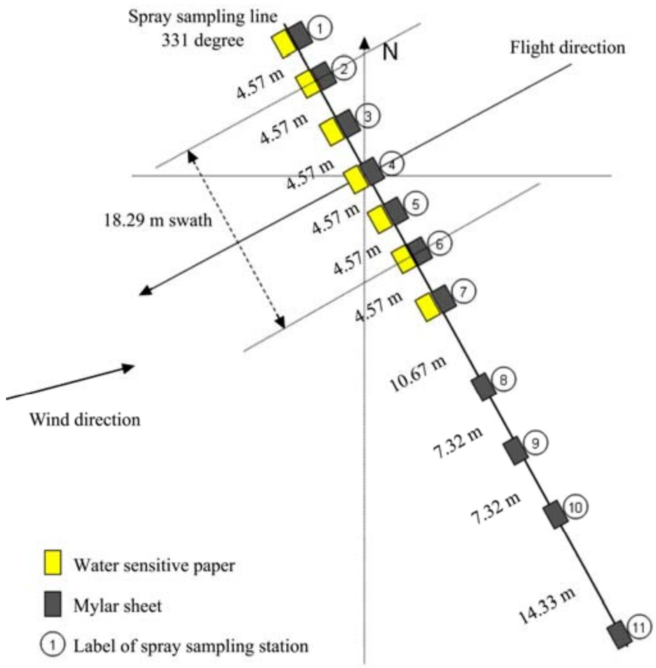
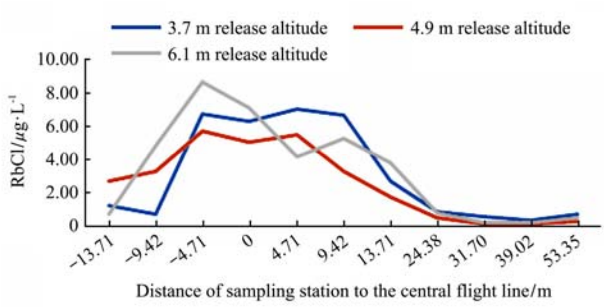


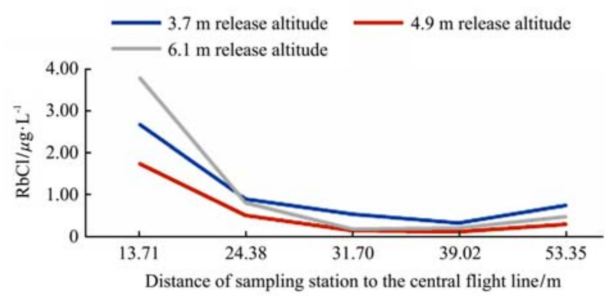
Figure 3 Experimental field layout for CP-11TT nozzle drift evaluation[12]

During the experiment, the airplane was planned to fly three passes with three replications at each of three different altitudes, 3.7 m, 4.9 m, and 6.1 m for a total of 27 flight runs and 165 Mylar sheets were collected.

The mixed-effect statistical model was built and implemented using spray sampling station location, applications release altitude, sampling station location applications release altitude as independent variables to evaluate the downwind deposition and drift effects of applications release altitude as indicated by RbCl concentration. The result indicated that sampling station location had a significant effect on RbCl concentration at the 1% level of significance with p=0.0004. However, application release altitude was not significant to the change of RbCl concentration. Figure 4a showed the insignificance of varied release altitudes to RbCl although RbCl concentrations consistently demonstrated a similar trend at different spray release altitudes with the locations of the sampling station in the spray swath and downwind further away from the central spray line. Figure 4 further presented that RbCl concentrations could well profile the degree and extent of the downwind drift, which is important for evaluation of the performance of the CP nozzles in control of off-target drift.



a. RbCl concentrations along the swath and downwind sampling stations



b. RbCl concentrations downwind the swath to represent off-target drift

Figure 4 CP nozzle drift assessment

3.2 RbCl tracer for assessment of crop injury from off-target drift of aerially applied glyphosate

This experiment used the same aerial application system to assess crop injury from the off-target drift of aerially applied glyphosate except of using fifty-four CP-09 spray nozzles (CP Products, Inc., Wichita Falls, Texas, USA) set at a 5° deflection angle[21].

Glyphosate is the most commonly applied herbicide either alone or with other herbicides to manage a broad spectrum of weeds. Glyphosate drift is particularly important because it is a non-selective herbicide and highly active on sensitive plant species at low doses[22]. This study was designed to assess soybean (*Glycine max*), cotton (*Gossypium* sp.) and corn (*Zea mays*) injury in the field from the off-target drift of aerially applied glyphosate[23-25].

The experiment was conducted on a 2 hm^2 field located at Stoneville, MS, USA (33°26’ N, 90°55’ W) on the farm of the USDA-ARS Research Service, Crop Production Systems Research Unit. For the experiment, non-glyphosate resistant (GR) cotton, corn and soybean were planted next to each other in eight 1.02 m-spaced, 80 m-long rows, respectively, with four replications (blocks) (Figure 5).

In the experiment the weather conditions were recorded with average wind speed of 11.2 km/h from the northeast direction at an average of 64^o from true north. Average air temperature was 28.5^{o}C and relative humidity was 72%.

The main spray sampling transect was established in the middle of the field north to south along the crop rows and perpendicular to the spray swath (Figure 5). The drift sampling stations with Mylar sheets were set on the sampling line from north to south at 0 m, 3 m, 6 m, 11 m, 16 m, 26 m and 35 m from the edge of the spray swath. For the experiment, the spray tank was mixed with glyphosate spray solutions using 540 g ae/L glyphosate-potassium salt (Roundup WeatherMax®, Monsanto Co., St Louis, Missouri, USA) at a rate of 866 g ae/hm^2 and 2.6 g RbCl tracer to allow proportional estimation of glyphosate concentrations downwind. Figure 6 demonstrates the measurement of RbCl concentrations downwind the spray swath and the model of the RbCl concentrations for estimation of glyphosate concentrations downwind.

RbCl concentrations measured from Mylar sheets were correlated with visual injury, plant height, shoot dry weight, leaf chlorophyll content, and shikimate, which were measured from the leaf and plant samples collected one, two and three weeks after glyphosate spray (WAG)[26]. The correlation study of the soybean, cotton and corn leaf physiological responses (shikimate and chlorophyll) with RbCl indicated that their physical responses (visual injury and plant height) could be used effectively to determine the injury to soybeans and cotton caused by the drift of aerially applied glyphosate at 1 and

2 WAG and the visual injury (corn plant height not available in 1 WAG) could be used to determine the injury to corn at 1 WAG[27]. Figure 6 shows the RbCl concentrations of the sampling stations downwind from the edge the swath with a good reciprocal curve fitting (R^2=0.99). Among all the biological responses, regardless of WAG, 12-26 m of the downwind off-swath distance was determined as the range of the lethal distance that the drift caused 50% reduction in these biological responses with 5.6% deposited glyphosate as inferred by integrated amounts of RbCl between 12 m and 26 m[28].

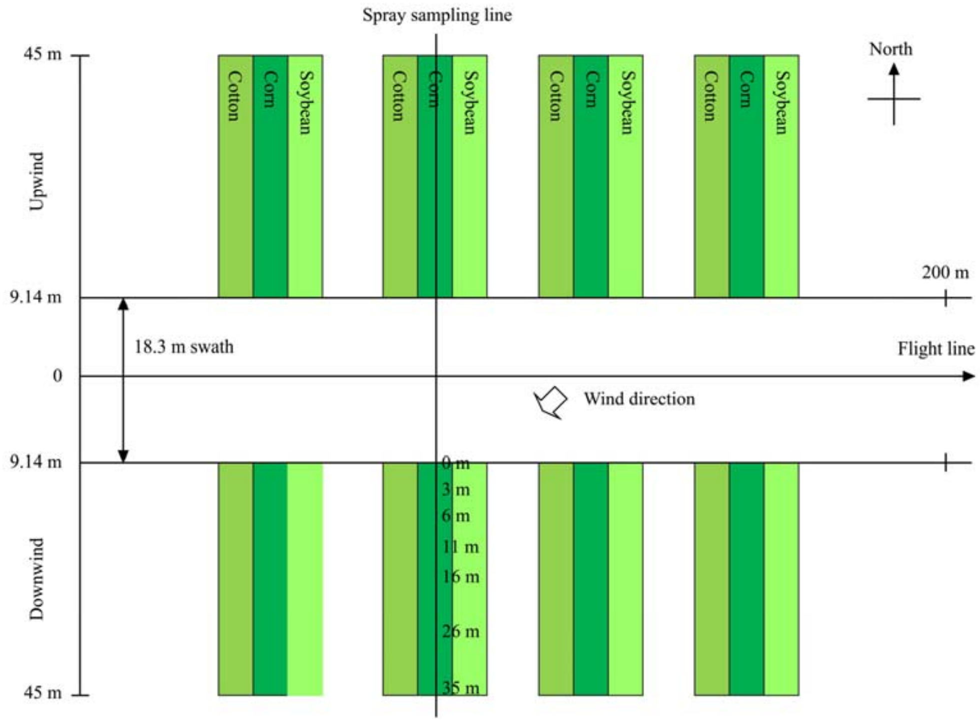


Figure 5 Experimental field layout for crop glyphosate-drift injury assessment

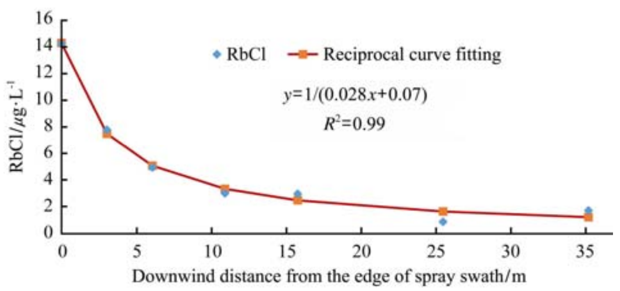


Figure 6 RbCl concentrations of the sampling stations downwind from the edge the swath with reciprocal curve fitting for crop injury assessment from the off-target drift of aerially applied glyphosate

4 Conclusions

As shown in the paper, RbCl, in overall, is an effective tracer used to monitor spray drifts to intensify agriculture output, while minimizing environmental impact. Specially, this paper demonstrated that the RbCl tracer method worked well for a low-drift nozzle evaluation and crop injury assessment from the off-target drift of aerially applied glyphosate. The current research was conducted on an agricultural aircraft. The method will be evaluated on unmanned aerial vehicles for low-volume sprays. Because agriculture intensification can spare more land for biodiversity conservation[29], more data collection and modeling will increase the precision and reduce further environmental impact.

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