Research Paper

Airborne remote sensing assessment of the damage to cotton caused by spray drift from aerially applied glyphosate through spray deposition measurements

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To identify the effects of aerially applied glyphosate on cotton plants, a field was planted with replicated blocks of cotton. To quantify relative deposits of applied chemical, spray samplers were placed in the spray swath and in several downwind orientations. An Air Tractor 402B spray aircraft, equipped with fifty-four CP-09 nozzles, was flown down the centre of the field to apply a mixture of 1.54 kg ha⁻¹ of glyphosate and rubidium chloride tracer at a 46.77 l ha⁻¹ application rate. At one week intervals following treatment, aerial colour-infrared imagery was obtained from the field using a global positioning system-triggered multispectral camera system. The processed drift and image data were highly correlated with correlation coefficients (r) from 0.38 to 0.97 at 1, 2, and 3 weeks after treatment. The drift and image data were used as the indicators of visual injury in regressions with a strong ability to explain variability (R² from 0.36 to 0.90 for drift data for the first week after treatment (WAT); from 0.20 to 0.90 for image data from 1, 2, to 3 WAT). The results illustrate that spray drift sampling can explain early cotton injury (1 WAT), and airborne remote sensing can explain late cotton injury (2 and 3 WAT). The results are helpful for determining the extent of required near-field drift sampling and demonstrate that airborne multispectral imaging can be a viable tool for determining the extent of damage relative to derived concentrations of glyphosate.

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1. Introduction

Aerial application of crop production and protection materials has been employed for effective crop management. However, the possibility of off-target drift from aerial application can be a problem not only for environmental pollution but also for potential injury to crops in neighbouring fields. Aerial spray drift has been studied with regard to factors such as spray droplet size, application release height, nozzle configurations, and weather (Fritz, Hoffmann & Lan, 2009; Hoffman, Fritz & Lan, 2009; Huang & Thomson, 2008; Huang, Zhan, Fritz, Thomson, & Fang, 2010b; Kirk, Rouse, Carlton, & Franz, 1991; Salyani & Cromwell, 1992; Smith, Bode, & Gerard, 2000; Wolf, Brethauer, & Gardisser, 2005).
Crop injury from glyphosate drift, or simulated glyphosate drift, has been reported for several crops such as corn (Buehring, Massey, & Reynolds, 2007; Brown et al., 2009; Ellis, Griffin, Linscombe, & Webster, 2003), soybean (Bellaloui, Reddy, Zablotowicz, & Mengistu, 2006), rice (Ellis et al., 2003; Koger et al., 2005), and peanut (Lassiter et al., 2007). Glyphosate is a broad-spectrum systemic herbicide used to kill weeds, especially perennial weeds. In the United States, glyphosate-resistant (GR) crops have been widely adopted and this has led to an unprecedented increase in glyphosate usage for weed control over recent years. Glyphosate is typically sprayed onto foliage and is absorbed through the plant leaves. Aerial application of glyphosate can rapidly cover large areas to provide timely and effective control of weeds in crop fields. However, glyphosate is a non-selective herbicide, and the off-target drift of aerially applied glyphosate is highly active on sensitive plant species even at low rates. Numerous studies have been conducted to determine the effect of glyphosate drift. Bird, Esterly, and Perry (1996) investigated the results of several aerial applications reported in the literature and trials performed in Texas, USA by Spray Drift Task Force (SDTF). It was shown that median values of pesticide deposition decreased from about 5% of the nominal application rate at 30 m downwind to about 0.5% at 150 m downwind during aerial applications. In a cropped field, Kirk (2000) found that aerial glyphosate applications resulted in downwind drift of 70% of the applied volume rate at 10 m, 29% at 20 m, 6% at 40 m, and 0.1% at 320 m, regardless of glyphosate formulation. In aerial applications in forestry, Payne (1993) measured the dispersal of a herbicide from crosswind swaths under various meteorological conditions.

It was shown that downwind drift from application of glyphosate decreased from 36% of the applied volume rate at 10 m, 0.3% at 50 m, to 0.2% at 200 m. The deposits decreased by 90% between 0 and 50 m downwind but showed a more gradual decrease between 50 and 200 m downwind. From the numerous studies that have examined droplet size, drift distance, and spray deposition of herbicides from aerial applications, Reddy et al. (2010) incorporated some of these data in a study of the biological effects of glyphosate drift arising from aerial application on non-GR maize.

Remote sensing has been widely used and developed in agriculture (Huang, Thomson, Lan, & Maas, 2010a; Lan, Huang, Martin, & Hoffmann, 2009; Pinter et al., 2003). For glyphosate drift, Rowland (2000) determined that low rates of glyphosate could reduce the yield of maize, and that stand height was one of the best indicators for estimating the degree of damage. If a crop is injured to the degree that height is limited and yield is decreased, perhaps a remotely sensed image could be used to detect these injury symptoms seemingly invisible to the naked eye. Henry, Shaw, Reddy, Bruce, and Tamhankar (2004) conducted research to determine whether hyperspectral remote sensing could be used to identify and quantify herbicide injury to crops. Soybean and maize plants were grown in 3.8-l pots to the five- to seven-leaf stage, at which time applications of non-selective herbicides were made. Visual injury estimates were made, and hyperspectral reflectance data were recorded 1, 4, and 7 days after application. Several analysis techniques including multiple indices, signature amplitude with spectral bands, and wavelet analysis were used to distinguish between herbicide-treated and non-treated plants. The results indicated that hyperspectral

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**Nomenclature**

**Abbreviations** (in alphabetical order)

- CCD: charge-coupled device
- CIR: colour-infrared
- GR: glyphosate-resistant
- NIR: near infrared RGB - red green blue
- SDTF: Spray Drift Task Force (USA)
- VMD: volume median diameter
- WAT: weeks after treatment
- WSP: water sensitive paper

**Variables** (in alphabetical order)

- % AC: percent droplet area coverage on each water sensitive card
- NDVI: normalised difference vegetation index
- NDVI_1WAT: normalised difference vegetation index one week after treatment
- NDVI_2WAT: normalised difference vegetation index two weeks after treatment
- NDVI_3WAT: normalised difference vegetation index three weeks after treatment
- No. Drops: number of drops on water sensitive card per unit area in cm²
- r: Linear correlation coefficient
- R²: coefficient of determination of regression model
- RbCl: relative concentration of rubidium chloride tracer (g l⁻¹)
- % VI: percent crop damage from visual inspection
- % VI_1WAT: percent visual inspection one week after treatment
- % VI_2WAT: percent visual inspection two weeks after treatment
- % VI_3WAT: percent visual inspection three weeks after treatment
reflectance could distinguish between healthy and injured plants to which herbicides had been applied.

This study examines the effect of glyphosate drift from aerial application on non-GR cotton by spray drift sampling and remote sensing. Specific objectives of this research were: to determine the in-swath deposition and downwind drift characteristic of aerially applied glyphosate to a single swath of 18.3 m at a rate of 866 g ha\(^{-1}\) and to determine the crop injury by the downwind drift of sprayed chemical using spray drift sampling and aerial multispectral imaging.

2. Materials and methods

2.1. Experimental field and spray experiment

A cropped field located at Stoneville, MS, USA (33°26’N, 90°55’W), at the U.S. Department of Agriculture-Agricultural Research Service, Crop Production Systems Research Unit research farms, was used to conduct an aerial application experiment to determine injury and biological responses to glyphosate drift on non-GR cotton.

For the experiment, non-GR cotton cultivar ‘FM955LL’ at 100,000 seed ha\(^{-1}\) was planted on July 23, 2009 in eight rows spaced 1.02 m apart and 80 m long with four replications (blocks). Fig. 1 shows the layout of the experiment field.

Aerial application of glyphosate was made over the crops in the field on August 12, 2009. An Air Tractor 402B aircraft (Air Tractor, Olney, TX, USA) equipped with fifty-four equally spaced (0.18 m between centres) CP-09 spray nozzles (CP Products, Tempe, AZ, USA) using the 0.125 orifice and a 5° downward deflection angle. Two 4.93 m booms were installed on each side of the aircraft each holding 27 nozzles.

Nominal operating pressure was 241 kPa, which gave a target droplet spectrum Volume Median Diameter (VMD) from manufacturer data as 300 μm. The aircraft was configured to deliver the liquid at the rate of 46.8 l ha\(^{-1}\) at a spray release height of 3.7 m and operating speed of 63 m s\(^{-1}\) over an 18.3 m wide spray swath. The sprayed liquid was a glyphosate solution of Roundup Weathermax® (Monsanto Co., St. Louis, MO, USA) applied at a rate of 866 g ai ha\(^{-1}\), with 2.6 g rubidium chloride (RbCl) tracer used in the tank mix. A single spray run, in the west to east direction at the centre of the field perpendicular to the crop rows, was made over a marked swath line (Fig. 1). Weather conditions were recorded during the period the aircraft flew over the field. The average wind speed was 11.2 km h\(^{-1}\) averaging 64° from true north. During the spray run average air temperature was 28.5 °C and relative humidity was 72% as measured using a Kestrel 4500 weather tracker mounted on

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Fig. 1 – Field layout for the spray test (drift sampling stations are indicated by direction: N = north, S = south, SE = southeast, SW = southwest).
Correlations coefficients (r) between % droplet area coverage on each WSP (% AC), number of drops on each WSP (No. Drops), and RbCl concentration on each Mylar sheet, and NDVI at 1, 2, and 3 WAT.

<table>
<thead>
<tr>
<th>Variables</th>
<th>% AC</th>
<th>No. Drops (cm⁻²)</th>
<th>RbCl (µg L⁻¹)</th>
<th>NDVI_1WAT</th>
<th>NDVI_2WAT</th>
<th>NDVI_3WAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>% AC</td>
<td>1</td>
<td>0.9106</td>
<td>0.8933</td>
<td>-0.3792</td>
<td>-0.5615</td>
<td>-0.8143</td>
</tr>
<tr>
<td>No. Drops (cm⁻²)</td>
<td>0.9106</td>
<td>1</td>
<td>0.9735</td>
<td>-0.5479</td>
<td>-0.7499</td>
<td>-0.9679</td>
</tr>
<tr>
<td>RbCl (µg L⁻¹)</td>
<td>0.8933</td>
<td>0.9735</td>
<td>1</td>
<td>-0.5964</td>
<td>-0.7419</td>
<td>-0.9311</td>
</tr>
</tbody>
</table>

2.2 Spray sampling and data processing

The main spray sampling transect was established north to south along the crop rows and perpendicular to the spray swath (Fig. 1). The in-swath and drift sampling stations were marked in one line from north to south at 0 m (C5), 3 m (C6), 6 m (C7), 9 m (C8), 12 m (C9), 15 m (S2), 20 m (S3), 25 m (S4), 35 m (S5) and 45 m (S6) measured from the flight line downwind in the 18.3 m swath. Additional downwind drift sampling stations were set up at 45° (southwest and southeast) orientations.

At each of the north–south spray sampling stations, C1–C9 and S2–S6, water sensitive paper (WSP) cards (Syngenta, Basel, Switzerland) were placed. Each blank WSP measured 76 × 50 mm and indicated the presence of droplets by a blue stain. WSPs were collected within five minutes of the spray run for subsequent analysis. In the laboratory, each WSP card was scanned using a camera-based imaging system and specially written SigmaScan 5.0 (Systat Software, Inc., San Jose, CA, USA) macros capable of determining parameters from each of the cards, including total and percentage card area covered by spray droplets, the diameter of each droplet, its compactness, and the total number of droplets on cards.

Mylar® (DuPont Teijin Films, Hopewell, VA, USA) sampling sheets were also placed at canopy level at every sampling station. Each Mylar sheet was a polyester based film with a matte translucent surface and dimensions of 130 × 127 mm. Along with the WSPs, Mylar sheets were collected after the spray run. To obtain concentration of RbCl (µg L⁻¹), the Mylar sheets were 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% aqueous HNO₃ solution, which was also used for the calibration blank. Chemical analysis was carried out using an Analyst 600 Atomic Absorption Spectrometer (Perkin Elmer, Waltham, MA, USA). The Analyst 600 is equipped with a transversely heated THGA graphite furnace AA with longitudinal Zeeman-effect background correction. The spectrometer and furnace are controlled using WinLab 32 software (Perkin Elmer, Waltham, MA, USA).

2.3 Plant sampling

In addition to the downwind drift sampling stations, C9, S2, S3, S4, S5, and S6, plant sampling stations were allocated throughout the four cotton blocks. The spray sampling station, C5, which was along the centre line of the flight, was allocated as an additional plant sampling location. Also, one upwind sample station (N5) at 35 m upwind of the flight line was included as a control (crop not exposed to glyphosate). These stations were established in all four replicate blocks (Fig. 1). At each plant sampling station percent visual injury were estimated on a weekly basis up to 3 weeks after treatment (WAT).

2.4 Aerial multispectral imaging

An MS 4100 camera (Geospatial Systems, Inc., West Henrietta, NY, USA) was used to image the crop field. The MS 4100 camera is a multispectral 3-CCD (charge-coupled device) colour/colour-infrared (CIR) digital camera. It provides a digital imaging quality with 1920 (horizontal) × 1080 (vertical) pixel array per sensor and a 60° field of view when fitted with 14 mm, f/2.8 lens. The camera is available in two spectral configurations: RGB (red green blue) for high quality colour imaging and

<table>
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<th>Table 2 – Logistic modeling of droplet area coverage, number of drops on WSP cards, and RbCl concentrations on Mylar sheets.</th>
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</thead>
<tbody>
<tr>
<td><strong>Dependent Variables</strong></td>
</tr>
<tr>
<td>% AC</td>
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<tr>
<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td>No. Drops (cm⁻²)</td>
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<td></td>
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<tr>
<td>RbCl (µg L⁻¹)</td>
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CIR for multispectral applications. The camera images four spectral bands from 400 to 1000 nm, and acquires near infrared (NIR) at 800 nm with 60 nm bandwidth, red at 670 nm with 40 nm bandwidth, green at 540 nm with 40 nm bandwidth, and blue at 460 nm with 45 nm bandwidth image planes. When running the RGB or CIR configuration individually, a base configuration supports any three-tap configuration running at 8 bits per colour plane (i.e. 24-bit RGB).

Following chemical application on August 12, 2009, the MS 4100 camera was mounted on the Air Tractor 402B aircraft to acquire CIR images in red, green and NIR bands over the experimental field. The images were acquired on August 13 and then on a weekly basis up to 3 WAT. Flight altitude was approximately 366 m above ground level based on the flight records obtained from aircraft guidance system log files. This configuration resulted in the ground spatial resolution of the images at 110 \( \times \) 200 mm pixel \(^{-1}\). The images were georeferenced and transformed to a normalised difference vegetation index (NDVI) image. NDVI is a useful tool for visualising crop canopy vigour (Myneni, Hall, Sellers, & Marshak, 1995; Sellers, 1985), and is calculated by the following equation:

\[
\text{NDVI} = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}}
\]

where NIR is the pixel value of the NIR band image in the CIR image, and Red is the corresponding pixel value of the red band image in the CIR image. On the NDVI image, the pixel values, i.e. NDVI values, at plant sampling points were sampled using ArcGIS (ESRI, Redlands, CA, USA) Spatial Analyst toolbox for analysis.

### 2.5. Statistical analysis

Spray deposits measured by WSP and Mylar were correlated to each other and with plant NDVI at plant sampling points. The downwind point deposited spray and NDVI were regressed with percent visual injury on a weekly basis up to 3 WAT. Correlations and regressions were calculated using SAS for Windows software (version 9.1.3) (SAS Institute Inc., Cary, NC, USA).

The percentage of applied glyphosate dose rate deposited at each downwind distance was estimated. For the calculation the downwind distance at discrete stations was considered as the independent variable and the drift sampling values such as droplet % area coverage and number of drops per unit area of 38 cm\(^2\) of each WSP card, and RbCl concentration on the Mylar sheets in the spray sampling lines were considered as

### Table 3 – Regressions of % AC, No. of drops per unit area, concentration of RbCl, and NDVI with % visual injury (% VI).

<table>
<thead>
<tr>
<th>Equation</th>
<th>( R^2 )</th>
</tr>
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<tbody>
<tr>
<td>% VI_1WAT = 27.449 + 28.038 \times % AC</td>
<td>0.60</td>
</tr>
<tr>
<td>% VI_2WAT = 25.116 + 18.664 \times % AC</td>
<td>0.46</td>
</tr>
<tr>
<td>% VI_3WAT = 39.02 + 40.57 \times % AC</td>
<td>0.36</td>
</tr>
<tr>
<td>% VI_1WAT = 17.164 + 0.1367 \times No. Drops</td>
<td>0.89</td>
</tr>
<tr>
<td>% VI_2WAT = 17.88 + 0.0935 \times No. Drops</td>
<td>0.73</td>
</tr>
<tr>
<td>% VI_3WAT = 19.885 + 0.2258 \times No. Drops</td>
<td>0.71</td>
</tr>
<tr>
<td>% VI_1WAT = 12.123 + 0.6502 \times RbCl</td>
<td>0.86</td>
</tr>
<tr>
<td>% VI_2WAT = 14.103 + 4.6358 \times RbCl</td>
<td>0.72</td>
</tr>
<tr>
<td>% VI_3WAT = 12.28 + 10.804 \times RbCl</td>
<td>0.66</td>
</tr>
<tr>
<td>% VI_1WAT = 42.989 – 106.57 \times NDVI_1WAT</td>
<td>0.21</td>
</tr>
<tr>
<td>% VI_2WAT = 44.447 – 163.02 \times NDVI_2WAT</td>
<td>0.85</td>
</tr>
<tr>
<td>% VI_3WAT = 104.91 – 348.51 \times NDVI_3WAT</td>
<td>0.90</td>
</tr>
</tbody>
</table>

\( R^2 \) is the coefficient of determination of each regression model to indicate the proportion of variability in a data set that is accounted for by the model.
dependent variables. The data were fitted to a logistic model to relate the drift sampling values ($y$) to downwind drift distance ($x$):

$$y = \frac{a}{1 + b e^{-c x}}$$

(2)

where $a$, $b$, and $c$ are fitting constants.

Different spray sampling methods can be compared for the field treatment using the distance that spray drift must travel to be reduced to 50% of the application volume. In this study, the spray sampling data were fitted to Eq. (2) to determine the 50% reduction distance. This distance was then converted into the distance between the 50% reduction distance and the edge of the swath.

Regression parameters for Eq. (2) were computed using CurveExpert 1.36 (Daniel Hyams, Starkville, MS, USA).

3. Results and discussion

3.1. Correlation between deposited spray and NDVI

Table 1 shows the linear correlation between the parameters of deposited spray: percent droplet coverage on each WSP, number of drops per unit area on each WSP, and RbCl concentration on each Mylar sheet, and NDVI at 1, 2, and 3 WAT. From the table it can be seen that on the WSPs the % droplet coverage and the number of drops per unit area were highly correlated ($r = 0.91$ where $r$ is the correlation coefficient). This was as expected because the two variables were measured using the same measuring method. Furthermore, % droplet coverage and the number of drops per unit area on the WSPs were highly correlated with RbCl concentration on the Mylar sheets ($r = 0.90$ and 0.97 respectively). This indicates that there is a consistency between the variables used to measure glyphosate deposits using the two different methods, and that RbCl concentration on Mylar may be more consistent than the % droplet coverage and the number of drops per unit area on the WSP for measuring the glyphosate deposit.

Table 1 also shows that NDVI has a strongly negative correlation with % droplet coverage, number of drops per unit area, and RbCl concentration, which reveals the expected result that less deposited chemical produces less crop damage as detected by remote sensing. As time after treatment increased from 1 WAT to 3 WAT, the strength of the correlations increased. This is likely due to a larger relative increase in crop vitality downwind of the spray swath later in the season. As correlated with RbCl ($r = -0.60$ to $-0.93$), NDVI had a strong correlation with number of drops per unit area ($r = -0.55$ to $-0.97$) as well as % droplet coverage ($r = -0.38$ to $-0.81$).

3.2. Logistic modeling to determine location of percent reduction of deposited spray

Logistic modeling results of droplet area coverage, the number of drops per unit area on WSP cards, the RbCl concentration, the downwind location of 50% reduction in deposited spray, and the distances between the location of 50% deposited spray reduction and the edge of the swath are given in Table 2. The plots of the regression model versus measured values are shown in Fig. 2. The two 50% reduction distances based on WSP measurements of droplet area coverage and the number...
of drops per unit area were calculated to be about 12.8 m (3.8 m from the edge of the swath). The 50% reduction distance was based on the RbCl deposition on the Mylar sheets was calculated to be about 13.1 m (4.1 m from the edge of the swath). These distance results from two different spray sampling methods were very similar. The two methods performed comparably in measuring the deposited drift of sprayed glyphosate with only a 2% level of difference.

3.3. Regressions of downwind-deposited spray and NDVI with percent visual injury

Table 3 illustrates regressions of % droplet area coverage, number of drops per unit area, concentration of RbCl, and NDVI with visual injury in the downwind drift direction. Results indicate that spray drift sampling is able to indicate crop injury early and the ability decreases with time (1 WAT to 3 WAT). This is probably because spray drift was measured on the day of field treatment and the drift data used to interpret crop injury were obtained near to the treatment day. The ability to predict measured values reduced with time. NDVI was different from spray drift sampling in explaining crop injury. The results indicated that NDVI explained crop injury well at 2 and 3 WAT. NDVI was extracted from the CIR images acquired at 1, 2, and 3 WAT, which followed the temporal relationship of the crop sampling at 1, 2, and 3 WAT. On the day of treatment the cotton was at two- to three-leaf stage, and the NDVI values were relatively low with a lot of soil interference at 1 WAT. From 2 WAT to 3 WAT the crop continued to grow and canopy developed gradually in the uninjured crop areas. The continued crop growth and gradually developed canopy and enhanced the contrast between the injured and the newly grown crop in the injured and uninjured crop areas. Later in the growing season the contrast could be clear enough for NDVI to be an effective tool to profile the growth gradient downwind in the field from the spray treatment.

The differentiation between the degrees of the spray drift injury of the cotton crop can be seen in Fig. 3 and Fig. 4. Fig. 3 shows the CIR images on 13 August (next day of the

Fig. 4 – NDVI images (a) one day after spray application; (b) 1 WAT; (c) 2 WAT; (d) 3 WAT. Greyscale from dark to white the images illustrate increased NDVI values to represent increased vigour of the crop canopy.
experiment) (Fig. 3 (a)) and 2 September 2009 (3 WAT) (Fig. 3 (b)) over the field area. Fig. 4 illustrates the NDVI images on 13 August and 1 WAT, 2 WAT, and 3 WAT over the crop sampling areas. The images (Fig. 4 (a)) on 13 August, the next day of spraying, did not show visible crop injury. At 1 WAT, the NDVI image (Fig. 4 (b)) indicates clear crop damage, which was more pronounced in the images at 2 WAT (Fig. 4 (c)) and 3 WAT (Fig. 4 (d)). Injury as indicated by imagery appeared to reduce with downwind (reddish colours in the CIR image illustrate increased vigour of the crop canopy).

4. Summary and conclusions

Percent droplet coverage and the number of drops per unit area on WSPs were highly correlated with RbCl concentration on Mylar ($r = 0.90$ and 0.97 respectively), which indicates that the consistency between the variables used to assess the sprayed glyphosate deposit using the two different methods. Logistic models were fit to data from the two different spray sampling methods. Results provided distances between the location of 50% reduction in deposited spray and the edge of the swath, with values of 3.8 m and 4.1 m for droplet density (WSP) and RbCl concentration, respectively. Similarity between these values suggests that either method could be suitable for quantifying spray drift deposit of aerially applied glyphosate with only a 2% level of difference. The relative concentration of RbCl tracer could be used to infer the concentration of active ingredient.

NDVI from aerial imagery had a strongly negative correlation with % droplet coverage ($r = -0.38$ to $-0.81$ from 1 WAT to 3 WAT), number of drops ($r = -0.55$ to $-0.97$ from 1 WAT to 3 WAT), and RbCl concentration ($r = -0.60$ to $-0.93$ from 1 WAT to 3 WAT). This illustrates an expected result that less deposited chemical produced less crop damage as detected by remote sensing downwind. With the time passing from 1 WAT to 3 WAT crop vitality increased relatively larger vitality downwind of the spray swath, which resulted in that the strength of the correlations increased. This illustrates that NDVI can explain the effects of the aerially applied glyphosate drift late in the crop growing season after field treatment.

The results of regressions of % droplet area coverage, number of drops per unit area, concentration of RbCl, and NDVI with % visual injury in the downwind drift direction indicate that spray drift sampling was able to explain early crop injury (i.e. 1 WAT). The advantage of airborne remote sensing is that it can be carried out following the temporal changes that occur over the field. From 1 WAT to 3 WAT the continued increased crop vitality downwind of the spray swath enhanced the contrast of the injured crops and the newly grown crops in injured and uninjured crop areas with relative large NDVI values at 2 and 3 WAT. It can be anticipated that within the period of crop growth (a few months) cotton crop vigour will be significant with regrowth of damaged crops and continued growth of undamaged crops with subsequent significantly higher NDVI. Therefore, NDVI can be a good tool to profile the growth gradient downwind from field treatment for evaluation of the effect of aerially applied glyphosate drift on non-GR cotton during the entire growing season following field treatment.

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