The effects of spray application rate and droplet size on applications to control soybean rust

Scott M Bretthauer, ASABE Member

University of Illinois at Urbana-Champaign, 1304 W. Pennsylvania Ave.,
Urbana, IL 61801, USA

Tristan A Mueller

Bayer Crop Science, 33224 H. Avenue, Earlham, IA 50072, USA

Richard C Derksen, ASABE Member

Heping Zhu, ASABE Member

USDA-ARS, Agricultural Engineering Building, 1680 Madison Avenue,
Wooster, OH 44691, USA

Loren E Bode, ASABE Member

University of Illinois at Urbana-Champaign, 1304 W. Pennsylvania Ave.,
Urbana, IL 61801, USA

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Abstract. Canopy penetration and thorough coverage are important when applying foliar fungicides to soybeans for the control of rust. The purpose of this study was to examine how spray application rate and spray droplet size affect the efficacy of soybean rust applications. Four treatments were examined: a medium droplet spectrum applied at 47 L/ha (5 GPA) and at 140 L/ha (15 GPA), and a very coarse droplet spectrum applied at 47 L/ha (5 GPA) and at 140 L/ha (15 GPA). Applications were made to soybeans planted with 91 cm (36 inch) row spacing in the R5 growth stage. Spray coverage, deposition, soybean rust severity, and yield were measured to evaluate the effectiveness of these treatments. Spray coverage was measured on Kromekote paper positioned in the upper and lower parts of the canopy. Deposition was measured using a dye and Mylar plates positioned in the upper and lower parts of the canopy. The very coarse droplet spectrum at 140 L/ha (15 GPA) had the highest coverage and deposition in both the upper and lower canopy. Overall the very coarse droplet spectrum performed better than the medium droplet spectrum. There was no difference among the treatments in soybean rust severity or yield. All the treatments had significantly lower soybean rust severity than an untreated control, and all but the very coarse droplet spectrum at 140 L/ha (15 GPA) had a significantly higher yield than the untreated control.

Keywords. Spray application rate, droplet size, coverage, deposition, soybean rust.

Introduction

Asian soybean rust (Phakopsora pachyrhizi) is a serious disease with the potential to substantially reduce soybean yields. Currently the only method of controlling the disease is the application of foliar fungicides (Ozkan et al., 2006). Soybean rust generally initiates in the lower portion of the soybean canopy and moves upward; thus canopy penetration and good coverage from spray applications are critical when applying fungicides to treat soybean rust (Wolf and Daggupati, 2006; Zhu et al., 2006; Bradley et al. 2007; Mueller, 2007).

Several studies have examined the effect of various nozzle types and other application technology on fungicide applications to soybeans. The focus of these studies was to maximize coverage and deposition in the lower parts of the canopy. Several of the studies used either 140 or 187 L/ha (15 or 20 GPA) spray application rates primarily applied from nozzle types, sizes, and pressures that provided a fine to medium droplet size spectrum (ASAE, 2004; Ozkan et al., 2006; Wolf and Daggupati, 2006; Zhu et al., 2006). Hanna et al. (2006) examined how application rates ranging from 112 to 187 L/ha (12 to 20 GPA) and droplet size spectrums ranging from fine to coarse affected fungicide applications to soybeans; they found no significant differences in spray coverage within the soybean canopy, disease severity, or yield. Since soybean rust was not present for these studies, results are based on how well the treatments covered artificial targets and affected yield based on
controlling other soybean diseases. Mueller (2007) found that an application rate of 187 L/ha (20 GPA) provided greater coverage in both the upper and lower parts of the canopy compared to a 94 L/ha (10 GPA) application rate, but there was no difference in yield or soybean rust severity between the two application rates.

**Objective**

The objective of this study was to determine how spray application rate and droplet size affect the efficacy of foliar applications of fungicide to soybeans for control of rust. Coverage, deposition, yield, and disease ratings were used to evaluate the effectiveness of the treatments.

**Materials and Methods**

Research was conducted at the North Florida Research and Education Center in Quincy, FL. The applications were made to soybean variety Delta Pine 7220RR that was planted on June 15, 2007 in four row plots with two rows border between plots. Plots were 15 m (50 feet) long and 4 rows wide with 91 cm (36 inch) row spacing. The soybean canopy was not closed at the time of application with average plant height of approximately 75 cm (30 inches). While not directly measured, the canopy density was much lower than that typically encountered in Midwestern soybeans.

A total of four application treatments plus a control were included in the study. Treatments included a medium (M) droplet spectrum (ASAE, 2004) at an application rate of 47 L/ha (5 GPA), a M droplet spectrum at 140 L/ha (15 GPA), a very coarse (VC) droplet spectrum at 47 L/ha (5 GPA), and a VC droplet spectrum at 140 L/ha (15 GPA) (Table 1). A M droplet spectrum nominally has a volume median diameter (VMD) between 250 and 350 microns, and a VC droplet spectrum nominally has a VMD between 450 and 550 microns. There were four replications for each treatment and the control for a total of 20 plots; the experimental design was completely randomized. Applications were made between noon and 3:00 pm on September 24, 2007. The soybeans were at growth stage R5. The fungicide Folicur 3.6F (tebuconazole) was applied at a rate of 292 ml/ha (4 fl oz/acre) for all applications. Average weather conditions, measured at a height of 10 m (33 ft), during the time the applications were: air temperature 30° C, relative humidity 55%, wind speed 17 KPH (10.3 mph), and wind direction 101°.

**Table 1. Treatments and parameters used for soybean rust study.**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Droplet spectrum</th>
<th>L/ha (GPA)</th>
<th>Nozzle*</th>
<th>kPa (psi)</th>
<th>Duty cycle**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Medium (M)</td>
<td>47 (5)</td>
<td>XR11004</td>
<td>159 (23)</td>
<td>30%</td>
</tr>
<tr>
<td>2</td>
<td>Medium (M)</td>
<td>140 (15)</td>
<td>XR11004</td>
<td>159 (23)</td>
<td>90%</td>
</tr>
</tbody>
</table>
The droplet size distributions for the two nozzles used in the study were measured using a droplet laser image analysis system (Oxford Lasers, Oxfordshire, U.K.). The droplet size distributions were measured for two nozzle tips of each type with three replications each. Droplet sizes were measured 33 cm (13 in) below the nozzle over a 40 cm (16 in) wide band centered on the nozzle. Droplet size data for these nozzles are presented in Table 2.

Table 2. Droplet size distribution measured at 33 cm (13 in) below the nozzle for nozzles used to create M and VC droplet spectrums.

<table>
<thead>
<tr>
<th>Droplet spectrum</th>
<th>Nozzle</th>
<th>kPa (psi)</th>
<th>D (V_{0.1}) (µm)</th>
<th>D (V_{0.5}) (µm)</th>
<th>D (V_{0.9}) (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium (M)</td>
<td>XR11004</td>
<td>159 (23)</td>
<td>97</td>
<td>224</td>
<td>461</td>
</tr>
</tbody>
</table>

Applications were made using a tractor mounted boom sprayer. All treatments were applied at 9.6 KPH (6 mph) with nozzles spaced at 46 cm (18 in). A SharpShooter pulse width modulation system (Capstan Ag Systems, Inc., Topeka, KS) was used to alter between the 47 L/ha (5 GPA) and 140 L/ha (15 GPA) application rates. The boom height was set for 51 cm (20 in) above the top of the soybean canopy. Table 1 shows the nozzle type and orifice size, pressure, and duty cycle for the four treatments. The right boom section was used to make the applications; the tractor was operated in the border rows on the edge of each plot for each application.

Spray coverage, defined as the percentage of a card’s total surface area turned pink by the dye, was sampled using 5 by 9 cm (2 by 3.5 in) Kromekote cards and Vision Pink dye (GarrCo Products Inc., Converse, IN) mixed at a rate of 0.95 L dye per 379 L spray solution (1 qt per 100 gal) for all treatments. Kromekote cards were placed on stainless steel plates attached to electric fence stakes at two positions within the soybean canopy: 18 cm (5 in) above the ground (referred to as lower position) and 50 cm (19.5 inches) above the ground (referred to as upper position). These positions were approximately one third and two thirds of the total plant height. Sampling was conducted in the
center two rows of each plot, with 10 stakes per row, spaced at 0.6 m (2 ft) intervals in the center 6 m (20 ft) of each row. Stakes were positioned directly in the soybean row to maximize plant coverage over the artificial targets. Plates were attached to stakes in a manner that minimized interference between the plates and stake. Cards were allowed to dry following the applications and then collected and stored in plastic sample bags. Coverage on each card was analyzed using DropletScan (WRK of Arkansas, Lonoke, AR; WRK of Oklahoma, Stillwater, OK). In addition to coverage, D_{0.1}, D_{0.5}, and D_{0.9} were calculated for the cards; the spread factor for water was used in these calculations.

Spray deposition, defined as the amount of tracer dye deposited per cm², was measured using Brilliant Sulfaflavine (BSF) (MP Biomedicals, Inc., Aurora, OH) mixed at a concentration of 2 g/L (0.26 oz/gal) for the two 140 L/ha (15 GPA) treatments and 6 g/L (0.80 oz/gal) for the two 47 L/ha (5 GPA) treatments. This represented a uniform application of 279 g/ha (4 oz/acre) for all treatments. Deposition of BSF was sampled using 2.5 by 7.6 cm (1 by 3 in) Mylar plates, placed on stainless steel plates attached to electric fence stakes, set at the same lower and upper positions in the canopy as the Kromekote cards. Samples were collected in the center 4 m (13 ft) of the center two rows of each plot, with 3 stakes per row set at 2 m (6.5 ft) intervals. Stakes were positioned directly in the soybean row to maximize plant coverage over the artificial targets. The plates were allowed to dry after the applications and then collected and stored in 125 ml plastic bottles, which were then stored in nontransparent plastic totes. The plates were washed and dissolved with 15 ml of purified water. A 4 ml sample of the rinsate was placed in a cuvette and measured for peak fluorescent intensity at an excitation wavelength of 460 nm using a Model LS 50B Luminescence Spectrometer (Perkin-Elmer Limited, Beaconsfield, Buckinghamshire, England). A sample was also tested to verify that the Vision Pink dye did not interfere with the BSF. A single sample fell outside of the calibration range; it was diluted further and re-measured. Fluorescent intensity was converted to the amount of BSF per unit area (µg/cm²).

Soybean rust ratings were taken for each plot on October 17, 2007. A visual assessment of soybean rust severity was done for each plot using a percentage scale. Yield was measured for each plot by harvesting the entire plot, weighing, adjusting for 13 percent moisture, and then calculating yield on a per hectare basis.

Data analysis was conducted with SAS 9.1 (SAS Institute, Cary, NC) using treatment as the single independent variable, i.e. four separate levels based on the combination of droplet size spectrum and spray application rate (Table 1). Yield and soybean rust rating data were analyzed with the analysis of variance (ANOVA) procedure with Fisher’s LSD used to compare means; alpha was set at 0.05. Coverage, D_{0.1}, D_{0.5}, and D_{0.9} data from the Kromekote cards was analyzed using the mixed models procedure (PROC MIXED) with treatment as the fixed effect and replication and individual card nested within replication as random effects; pairwise differences of least squares means were calculated for each combination of treatments (Fritz et al., 2006). The upper and lower data sets were analyzed separately, as a decrease from the upper to lower canopy was assumed. Deposition data was analyzed using the mixed models procedure (PROC MIXED) with treatment as the fixed effect and replication and individual plate nested within replication as random effects; pairwise differences of least squares means were calculated for each combination of treatments. The upper and lower data sets were analyzed separately, as a decrease from the upper to lower canopy was assumed.

Results
The effects of the four treatments on coverage are summarized in Table 3. Not surprisingly, the two 140 L/ha (15 GPA) treatments resulted in significantly greater coverage than the 47 L/ha (5 GPA) treatments at both canopy levels. The VC droplet spectrum applied at 140 L/ha (15 GPA) resulted in the greatest coverage in both the lower and upper portions of the canopy. In the lower portion of the canopy, the M droplet spectrum at 47 L/ha (5 GPA) and the VC droplet spectrum at 47 L/ha (5 GPA) had the same coverage. In the upper part of the canopy, for both the 47 L/ha (5 GPA) and 140 L/ha (15 GPA) treatments, the VC droplet spectrum provided higher coverage than the M droplet spectrum. In the lower part of the canopy, this was only true for the 140 L/ha (15 GPA) treatments.

Table 3. Percent coverage for the four treatments in upper and lower portions of the canopy.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Droplet Spectrum</th>
<th>L/ha (GPA)</th>
<th>Upper canopy (coverage)</th>
<th>Lower canopy (coverage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Medium (M)</td>
<td>47 (5)</td>
<td>4.3d</td>
<td>1.4c</td>
</tr>
<tr>
<td>2</td>
<td>Medium (M)</td>
<td>140 (15)</td>
<td>10.9b</td>
<td>2.6b</td>
</tr>
<tr>
<td>3</td>
<td>Very coarse (VC)</td>
<td>47 (5)</td>
<td>5.8c</td>
<td>1.8c</td>
</tr>
<tr>
<td>4</td>
<td>Very coarse (VC)</td>
<td>140 (15)</td>
<td>12.5a</td>
<td>3.8a</td>
</tr>
</tbody>
</table>

Different letters indicate significance at alpha = 0.05

The droplet size distribution for the portion of the spray volume that reached the upper and lower cards is presented in Table 4. With the exception of \( D_{V0.5} \) in the lower canopy, all the droplet size distributions on the cards in both the lower and upper canopies were significantly different between all the treatments. In the lower canopy, the \( D_{V0.5} \) values for the two VC droplet spectrum treatments were not significantly different.

Table 4. \( D_{V0.1} \), \( D_{V0.5} \), and \( D_{V0.9} \) values, in microns, for the portion of the total spray volume that deposited on the upper and lower cards for the four treatments.
Different letters indicate significance at alpha = 0.05

Results of the deposition analysis are summarized in Table 5. Similar to the coverage results, the VC droplet spectrum applied at 140 L/ha (15 GPA) resulted in the highest deposition in both the lower and upper portions of the canopy. In the lower portion of the canopy, deposition for the M droplet spectrum at 140 L/ha (15 GPA) treatment and the VC droplet spectrum at 47 L/ha (5 GPA) treatment were not significantly different. For the two 140 L/ha (15 GPA) treatments, deposition was higher in both the upper and lower portions of the canopy when applied with the VC droplet spectrum compared to the M droplet spectrum; there was no difference between droplet spectrums at 47 L/ha (5 GPA).

Table 5. Deposition of BSF on artificial targets for the four treatments in upper and lower portions of the canopy.
Different letters indicate significance at alpha = 0.05

For soybean rust ratings (SBRR), the four treatments had a significantly lower soybean rust rating compared to the control; there were no differences among treatments (Table 6). Except for the VC droplet spectrum at 140 L/ha (15 GPA), yield was significantly higher in the treated plots compared to the untreated control, with no significant differences between the treatments (Table 6).

Table 6. Soybean rust ratings (SBRR) and yields for the four treatments and control.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Droplet Spectrum</th>
<th>L/ha (GPA)</th>
<th>SBRR*</th>
<th>kg/ha (bu/ac)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Medium (M)</td>
<td>47 (5)</td>
<td>2a</td>
<td>2829 (42.1) a</td>
</tr>
<tr>
<td>2</td>
<td>Medium (M)</td>
<td>140 (15)</td>
<td>1a</td>
<td>2889 (43.0) a</td>
</tr>
<tr>
<td>3</td>
<td>Very coarse (VC)</td>
<td>47 (5)</td>
<td>3a</td>
<td>2748 (40.9) a</td>
</tr>
<tr>
<td>4</td>
<td>Very coarse (VC)</td>
<td>140 (15)</td>
<td>2a</td>
<td>2641 (39.3) ab</td>
</tr>
<tr>
<td>5</td>
<td>Control</td>
<td>Control</td>
<td>50b</td>
<td>2372 (35.3) b</td>
</tr>
</tbody>
</table>

Different letters indicate significance at alpha = 0.05

*Ratings were taken on October 17, 2007.

**Discussion**

In this study a VC droplet spectrum provided better coverage and deposition than a M droplet spectrum when applied at 140 L/ha (15 GPA), and equal coverage and deposition to a M droplet spectrum when applied at 47 L/ha (5 GPA). This differs from the recommendations for soybean rust...
applications and the results of some researchers (Ozkan et al., 2006; Ozkan et al. 2007). While the M droplet spectrum at 140 L/ha (15 GPA) had significantly higher coverage in the lower portion of the canopy then the VC droplet spectrum at 47 L/ha (5 GPA), deposition in the lower canopy for the two treatments was not different. Despite significant differences in coverage and deposition between the treatments, there were no differences for soybean rust severity or yield.

Prior to the experiment, it was hypothesized that a M droplet spectrum at 140 L/ha (15 GPA) would provide the highest coverage and deposition, a VC droplet spectrum at 47 L/ha (5 GPA) would provide the lowest coverage and deposition, and the M droplet spectrum at 47 L/ha (5 GPA) and VC droplet spectrum at 140 L/ha (15 GPA) would be somewhere between the other two treatments. The better performance of the VC droplet spectrum compared to the M droplet spectrum in this study may be related to the very open canopy and the small droplet size of the M droplet spectrum used in this study, which was on the lower end of the recommended $D_{V0.5}$ range of 200-300 microns for soybean rust applications (Wolf and Daggupati, 2006; Ozkan et al. 2007). In addition, the warm and windy weather conditions would have favored the VC droplet spectrum over the M droplet spectrum. These factors may have made it more feasible for the VC droplet spectrum, compared to the M droplet spectrum, to penetrate into the soybean canopy.

A comparison of the droplet size distributions created at the nozzle (Table 2) and the droplet size distributions that deposited on the Kromekote cards (Table 4) supports this theory. When making this comparison, however, it must be noted that these distributions were measured with different systems, which means any differences cannot be solely attributed to application factors. For the M droplet spectrum, the Kromekote card $D_{V0.1}$, $D_{V0.5}$, and $D_{V0.9}$ values were much higher than what was measured at the nozzle. For the VC droplet spectrum, the $D_{V0.1}$ values were much higher, the $D_{V0.5}$ values slightly higher, and the $D_{V0.9}$ values lower for the cards as compared to what was measured at the nozzle. The card $D_{V0.5}$ values for the M droplet spectrum are closer to the at the nozzle $D_{V0.5}$ value for the VC droplet spectrum than to the at the nozzle $D_{V0.5}$ value for the M droplet spectrum. The droplet size distributions from the cards suggest that the larger droplets, more prevalent in the VC droplet spectrum, did a better job of penetrating the canopy and depositing on the cards.

Bradley et al. (2007) found an increase in coverage in the lower part of the canopy with increasing droplet size during one year of their study. Mueller (2007) found that VC and coarse droplet spectrums provided the same coverage as M droplet spectrums in the lower part of the soybean canopy. In cotton, Sumner et al. (2007) found that larger droplet sizes tended to increase coverage in the lower part of the canopy.

Also of note is that the droplet size distribution values from both the upper and lower cards for the four treatments were all significantly different from each other, with the exception of $D_{V0.5}$ for the two VC droplet spectrum treatments in the lower part of the canopy. Thus, as far as what deposited on the cards, the two M droplet spectrums were not identical, nor were the two VC droplet spectrums. It seems the change in duty cycle used to alter between the two application rates may have affected droplet size, at least in terms of what deposited on the cards.

Another explanation for the better coverage and deposition for the VC droplet spectrum might be the
fact that it occurred on flat, horizontally positioned artificial collectors. The larger droplets of the VC spectrum may not have deposited as well on actual leaves, either bouncing or rolling off. This might explain why the higher coverage and deposition seen with the VC droplet spectrum did not result in lower soybean rust ratings or higher yields than with the M droplet spectrum.

While the increase in coverage when comparing the 47 L/ha (5 GPA) to the 140 L/ha (15 GPA) treatments for both the M and VC droplet spectrums is not unexpected, the similar trend in deposition significantly increasing with an increase in spray application volume is unexpected. While the higher application rate significantly increased coverage for the both the M and VC droplet spectrums, the 47 L/ha (5 GPA) tank mixture had 3 times the concentration of BSF, which theoretically should mean similar depositions of BSF between the 47 L/ha (5 GPA) and 140 L/ha (15 GPA) treatments for both droplet spectrums.

For the M droplet spectrum, the explanation for the increased deposition at 140 L/ha (15 GPA) might be related to the M droplet spectrum’s reduced performance compared to the VC droplet spectrum, as previously mentioned. The M droplet spectrum was too small to effectively penetrate the canopy and deposit. For the VC droplet spectrum, the larger droplet size likely requires a higher spray application rate in order to provide adequate coverage on the target. In this case, the 47 L/ha (5 GPA) rate was too low with this large droplet size to provide comparable deposition to the 140 L/ha (15 GPA) treatment.

**Conclusion**

A VC droplet spectrum at 140 L/ha (15 GPA) provided better coverage and deposition than a VC droplet spectrum at 47 L/ha (5 GPA), or M droplet spectrums applied at either 47 L/ha (5 GPA) or 140 L/ha (15 GPA). Overall, a VC droplet spectrum provided better spray coverage and deposition than a M droplet spectrum. There were no differences among these treatments in terms of soybean rust severity or yield. However, since the soybean canopy was very open and not typical of Midwestern soybean fields, current recommendations for a M droplet spectrum and a minimum ground spray application rate of 140 L/ha (15 GPA) should not be altered. However, these results suggest that soybean rust can be controlled when applications are made with a variety of droplet sizes and spray application rates.

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**Disclaimer**

References to commercial products or trade names do not constitute an endorsement by the University of Illinois or USDA-ARS and do not imply discrimination against similar products.

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