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Effects of air-assisted and conventional spray delivery systems on management of soybean diseases[1]

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Summary

Sclerotinia Stem Rot (SSR) is a major soybean disease in the north central region of the United States. Asian Soybean Rust (ASR) is a looming threat to the industry. The primary infection site is flower petals for SSR and leaves for ASR. Infection for both diseases tends to occur in areas with higher moisture retention. SSR and ASR field trials were conducted in narrow and wide-spaced soybean planting systems. Application techniques included air-assisted delivery and conventional broadcast application using air induction, hollow cone, and traditional flat-fan nozzles. Slower travel speeds and an air-assisted sprayer produced the highest deposits in the SSR trial. There were no differences in deposits between conventional, broadcast sprayer treatments in the SSR trial. Air-assisted delivery and using mechanical means to open the canopy ahead of the spray pattern resulted in higher spray deposits in the middle and lower sections of the canopy in the ASR trials.

Key words: Soybean, Sclerotinia Stem Rot, Asian Soybean Rust, spray, air-assist

Introduction

Severe outbreaks of Sclerotinia stem rot (SSR) occurred in the north central region of the USA in 1992, 1994 and 1996 (Grau *et al.*, 1994; Hartman *et al.*, 1998; Hoffman *et al.*,1998). Flower petals are the initial site of SSR infection. Current soybean disease management programs provide recommended limits for rates of active ingredients, but little additional information on selecting appropriate delivery methods. Asian soybean rust (ASR) is a foliar disease that initially surfaced and remained for many years in Asian countries such as Taiwan, Thailand, Japan and India. More recently, it has occurred in South Africa, Paraguay, Brazil and Argentina. *Phakopsora pachyrhizi* is one the most aggressive of the fungal species known to cause soybean rust. Soybean rust causes premature defoliation, which leads to yield losses, fewer seeds per pod, decreased number of filled pods per plant and early maturity (Dorrance *et al.*, 2004). Soybean yield losses due to rust vary from negligible to complete loss of the crop. Variations in yield losses depend on the severity of the disease outbreak, the timing of the infection, selection of fungicides and timely, effective application of fungicides. A conservative prediction indicated yield losses greater than 10% in nearly all the U.S. soybean growing areas with losses up to 50% in the Mississippi delta and southeastern coastal states after soybean rust is introduced to the regions (Yeh *et al.*, 1981).

The objective of this research was to evaluate the efficacy and deposition efficiency of various fungicide application methods to protect against infection that could result in soybean crop yield loss. Delivery parameters were evaluated by characterizing spray deposition on artificial targets representing flower buds or leaves.

Materials and Methods

SSR management

In trials conducted in two separate years, food coloring was applied to soybeans to mimic application of fungicides that protect against Sclerotinia Stem Rot. Table 1 describes treatments and operating parameters.

Table 1. *Sprayers and operating parameters used in 1998 and 2000 Sclerotinia stem rot trials*

Treatment				Droplet size distribution		
Sprayer	Nozzle	Pressure (kPa)	Speed (km h^{-1})	$D_{V0.1}$ (μm)	$D_{V0.5}$ (μm)	$D_{V0.9}$ (μm)
Myers air-assist	XR110015	193	5.0	93	170	254
Myers air-assist	XR110015	758	10.0	68	139	214
Conv. Broadcast	XR8002	345	5.0	93	175	313
Conv. Broadcast	XR8004	345	10.0	116	225	448
Conv. Broadcast	AI11003	530	10.0	157	359	724
Conv. Broadcast	D2-23	1655	5.0	96	141	190
Conv. Broadcast	D3-25	1585	10.0	124	160	216

The air speed at the outlet of the Myers sprayer was 20 m s^{-1} with the boom centered in the air outlet of the sprayer and directed down and approximately 30° back from vertical. A three-point hitch plot sprayer with a 3 m off-set spray boom served as the conventional boom sprayer. The target plant was the Croton 3.9 soybean. The plant height ranged from 76–86 cm. FD&C Blue Dye No. 1 was mixed to a concentration of 1.5 g L^{-1} in the tank mix. Spray applications were made at 187 L ha^{-1}. Experiments were conducted at the R2 development stage as flower buds become visible because it is most important to protect the flower buds from infection.

Map tacks (6.3 mm diameter) were used as a target that closely resembled the size of flower buds. The metal pin of the map tack was inserted to a depth that kept the head of the tack from touching the soybean stem while not allowing the point of the pin to extend through the stem. This required angling the pin with relation to the stem. Each location consisted of two pins inserted on opposite sides of the stem near a flower bud. Targets were placed at two sets of locations: 30 cm above the ground (lower elevation) and 50 cm above the ground (middle elevation). Treatments were organized in a randomized block design with five replications. Each test plot was 4.5 m × 15 m. Following application of the tracer tank mix, each pair of targets at each elevation was placed in 125 mL glass sample bottles. Each pair from each elevation was analysed as a single sample. Tracer was recovered from the targets by rinsing them with 4 mL of distilled water and shaking each sample bottle 20 times. A Perkin-Elmer, Lambda 10, UV/Vis Spectrophotometer was used to measure the absorbance of each sample at an excitation wavelength of 629 nm.

An analysis of variance of the spray deposition was completed using PROC GLM in SAS with replications designated as a random effect and application method as the fixed effect. Means were separated with the Fisher's protected least significant differences test at $P \leq 0.05$.

ASR management

The foliar spray deposition was evaluated using 10 different spray techniques including two air-assisted sprayers, a pre-mixed air and liquid sprayer, and a conventional boom sprayer with seven different nozzles and a self-designed canopy opener (Table 2). (Design of the canopy opener is described below.) Travel speeds and application rates are shown in Table 2. The two air-assisted boom sprayers were manufactured by Jacto and Gregson. The Jacto sprayer had a 7.9 m long air sleeve and boom on each side and the Gregson sprayer had a 13.4 m long air bag and boom on each side. The air jet from the Jacto sprayer was delivered at a 58° angle toward the liquid spray pattern which was being directed vertically toward the canopies. The Jacto sprayer used JA3 hollow cone nozzles and the Gregson sprayer used XR8004 flat fan nozzles. Unverferth Equipment Co. provided the Top Air boom sprayer with a Spraying Systems Co., AirJet, pre-mixed air and liquid nozzle. The air and liquid were mixed in a chamber in the AirJet nozzle system before discharge from the nozzle orifice. The sprayer was operated at 290 kPa for liquid pressure and 185 kPa for the air pressure during the tests.

A three-point hitch plot sprayer with a 3 m off-set spray boom served as the conventional boom sprayer. Nozzles tested with the boom sprayer (Table 2) included three conventional flat fan nozzles (XR8002, XR8004 and XR8005) representing fine, medium and coarse spray qualities, a twin pattern nozzle (TJ60-8004), a Turbo Dual nozzle body containing two pre-orifice flat fan tips

Table 2. *Sprayers and operating parameters used in Asian Soybean Rust trials.*

Treatment		Pressure	Speed	Flow	Spray
Sprayer	Nozzle	(kPa)	(km h^{-1})	(L m^{-1})	Quality
Jacto air-assist sprayer	Jacto JA3	1062	11.3	1.32	fine
Top Air sprayer	Air pre-mixed	*	11.3	1.32	medium
Gregson air-assist sprayer	XR8004	193	11.3	1.32	fine
Boom sprayer	XR8004	214	11.3	1.32	medium
Boom sprayer	XR8002	290	6.4	0.76	fine
Boom sprayer	XR8005	138	11.3	1.32	coarse
Boom sprayer	Turbo Dual QJ90-TT11002	214	11.3	1.32	medium
Boom sprayer	TJ60-8004	214	11.3	1.32	medium
Boom sprayer	TX-18	372	11.3	1.32	medium
Boom sprayer with canopy opener	XR8004	214	11.3	1.32	medium

*290 kPa for liquid pressure and 185 kPa for air pressure

(QJ90-2XTT11002) and a hollow cone nozzle (TX-18). The Turbo Dual nozzle assembly produced two flat spray patterns with one spray pattern at 45° angle forward of vertical and another spray pattern at a 45° angle backward from the sprayer travel direction.

The mechanical canopy opener was fabricated to bend and open the canopy ahead of the spray pattern on the machine used to represent the conventional boom sprayer. This device was used to evaluate techniques for improving spray penetration into a soybean canopy. The canopy opener consisted of a length of electrical conduit pipe with a 3.2 cm outside diameter that extended the length of the spray boom. The conduit pipe was mounted 56 cm below and 25 cm upstream of the nozzles. Only the flat fan XR 8004 nozzles were used for the test with the canopy opener.

ASR deposition experiments were conducted in drilled bean canopies with 18 cm row spacing. The average height of soybean plants was 96 cm at the time of the tests and they had reached the R3 development stage. Each plot was 46 m long and 4.6 m wide. Treatments were organised in a randomised block design with four replications.

Three stakes for supporting artificial targets were placed 17, 23 and 29 m from the beginning edge of each plot. The artificial targets were 2.5 × 7.5 cm sheet metal plates. The targets were used to collect spray deposits inside canopies representing leaves. The artificial targets were positioned 30 cm and 60 cm above the ground, representing the bottom and middle parts of canopies, respectively. Two plates separated at a 180° angle were used to collect spray deposits at each height. The artificial targets were mounted horizontally with their longer dimension normal to the stake and with 90° radial separation from each other at each height. The midpoint of each plate was 11 cm from the stake. The artificial targets were oriented to avoid overlapping between two heights.

The application rate for all treatments was adjusted by either travel speed or flow rate to 145 L ha^{-1} (Table 2). A spray mixture containing water and Brilliant Sulfaflavine at a concentration of 2 g L^{-1} was used for all treatments. The artificial targets were collected 5 minutes after spraying. The plates were stored in 125-ml wide-mouth glass bottles in non-transparent boxes.

Spray deposits on metal plates were washed and dissolved in 20 mL of purified water (prepared with the Barnstead Mega-pure System, Model MP-12A). Then a 4 mL sample solution was placed in a cuvette for determination of peak fluorescent intensity with a Model LS 50B Luminescence Spectrometer at an excitation wavelength of 460 nm. If a sample concentration fell outside the calibration range, it was further diluted and measured again.

Data were analyzed by one way ANOVA and differences among means were determined with Duncan's New Multiple-Range Test using the ProStat version 3.8 (Poly Software International, Inc., Pearl River, NY). All significant differences were determined at the 0.05 level of significance.

Except for the Top Air sprayer, droplet sizes from nozzles used in the tests were measured with the Oxford Lasers VisiSizer particle/droplet image analysis system. Droplet size distributions were determined 0.3 m below the nozzle orifice across the centerline of the spray pattern width. A minimum 10 000 droplets were counted at each sampling position for the droplet size distribution analysis. Drop size measurements were made without the aid of any air-assisted delivery for the nozzles from the Jacto and Gregson sprayers.

Results

SSR management

The results from the two years of SSR experiments were not combined since there were significant differences in the canopy density due to differences in row spacing (Table 3). Because of limitations of the spray equipment and tractor, the spray booms were usually operated very close to the bean canopies in both years. Boom heights are commonly set higher than those used in these trials. However, raising the booms 40–50 cm over the canopies would have likely decreased spray penetration. In 1998, the air-assisted sprayer produced significantly higher deposits at both elevations, this despite the fact that the air/spray stream was directed back rather than straight down into the canopy. Also in 1998, the high pressure treatment (D2–23) did not appear to improve penetration and deposition lower in the canopy compared to the relatively low pressure, flat fan nozzle treatment. The drilled canopy of 2000 produced some differences in results compared by the 1998 tests but the trends appear to be similar.

Overall in 2000, the slower speed, air-assisted treatments produced numerically higher deposits at

Table 3. *Results of 1998 and 2000 Sclerotinia stem rot spray retention experiments.*

				1998[a] Deposits[c]		2000[b] Deposits[c]	
Sprayer Treatment	Nozzle	Pressure (kPa)	Speed ($km\ h^{-1}$)	Middle Canopy	Lower Canopy	Middle Canopy	Lower Canopy
Myers air-assist	XR110015	193	5.0	725.7 a[d]	397.0 a	322.3 a	221.8 a
Myers air-assist	XR110015	758	10.0	-	-	128.8 b	70.2 b c
Conv. Broadcast	XR8002	345	5.0	267.3 b	188.6 b	226.9 a b	172.2 a b
Conv. Broadcast	XR8004	345	10.0	-	-	210.2 a b	155.5 a b
Conv. Broadcast	AI11003	530	10.0	-	-	236.2 a b	84.0 b c
Conv. Broadcast	D2-23	1655	5.0	232.7 b	158.0 b	146.4 b	118.1 b c
Conv. Broadcast	D3-25	1585	10.0	-	-	177.1 a b	46.8 c

[a] 76 cm row spacing
[b] 18 cm row spacing
[c] Deposits reported in units of nanograms cm^{-2}
[d] Numbers in the same column followed by the same letter are not significantly different from each other ($P > 0.05$)

[a] 76 cm row spacing
[b] 18 cm row spacing
[c] Deposits reported in units of nanograms cm^{-2}
[d] Numbers in the same column followed by the same letter are not significantly different from each other ($P > 0.05$)

both elevations but the results were not significantly different from several of the other treatments. Speed had a significant affect on the performance of the Myers air-assisted sprayer. It appears that the air/spray delivery system was not well matched to the drilled bean canopy at the faster travel speed. This is likely to be because there was not sufficient energy in the air stream to overcome the deflection of the air jet at the faster travel speed. Since the Myers sprayer produced a rather fine spray droplet spectrum at the faster travel speed, these droplets would not have had sufficient kinetic energy to be delivered deep into the canopy. In general, the results show that faster travel speeds reduced spray deposits, particularly closer to the ground. The large droplets from the AI11003 nozzle were able to produce similar deposits in the middle canopy area as the other fan nozzle treatments but were not able to provide similar deposits closer to the ground. This might have been the result of a lower potential for coverage by the AI11003 nozzle with its coarse spray droplet spectrum and reduced chances for deposition in the target area. As in 1998, the high pressure, cone nozzles did not perform any better than lower pressure nozzle treatments and generally produced lower deposits.

ASR management

The Jacto JA3 nozzles produced smaller droplets to the XR8004 nozzles on the Gregson air-assist sprayer ($D_{V0.5}$ 118 vs. 335 μm). The average air speed near the air outlet and 33 cm below the nozzle was 33.1 and 9.8 m s^{-1} respectively for the Jacto sprayer and 15.9 and 3.7 m s^{-1} respectively for the Gregson sprayer. The nozzles used on the conventional boom sprayer produced $D_{V0.5}$ in the order from smallest to largest as hollow cone, XR8002, TwinJet60-8004, XR8004, Turbo Dual pattern and XR8005.

The average spray deposits in the middle of the canopy (or 60 cm above the ground) varied from 7.7% to 19.6% of the application rate among the 10 treatments (Fig. 1). The Jacto sprayer produced the highest spray deposits at the middle part inside canopies, followed by the Top Air sprayer and the boom sprayer with the canopy opener. The boom sprayer with hollow cone nozzles produced the lowest spray deposits at the middle part inside canopies, followed by Turbo Dual pattern and then XR8002 nozzles.

The average spray deposits at the bottom part of soybean canopies (or 30 cm above the ground) varied from 1.2% to 6.9% of the application rate among the 10 treatments (Fig. 2). Similarly to the deposition at the middle part of the canopies, of the 10 treatments, the Jacto sprayer provided the highest spray deposition at the bottom part inside canopies, followed by the Top Air sprayer and the boom sprayer with the canopy opener. The boom sprayer with hollow cone nozzles produced the lowest spray deposition at the bottom part inside canopies, followed by TwinJet and then Turbo dual pattern nozzles. The slower travel speed of the XR8002 nozzle treatment (fine spray quality) may have helped it achieve greater penetration and produce higher deposits in the bottom part of the soybean canopy compared to the other six conventional sprayer treatments.

Compared to the boom sprayer with XR8004 nozzles, the canopy opener increased spray deposits at both middle and bottom parts inside canopies (Figs 1 and 2). At the developmental growth stage R3, most soybean leaves were at the top part of plants and these leaves covered most area of the field. The average leaf area index of soybean canopies was 6.4 during the spray tests. With such high canopy density, most spray droplets from nozzles were intercepted by top leaves. With the help of the canopy opener to push the top part of canopies open, spray droplets would have more space to reach middle and bottom canopy levels, resulting in higher spray deposits in those locations.

The XR8002 flat fan nozzle treatment, with its slower travel speed, produced relatively high spray deposits at the bottom part of canopies compared to other hydraulic nozzles used at faster travel speeds. With a slower forward travel speed, droplets had a greater chance to reach targets

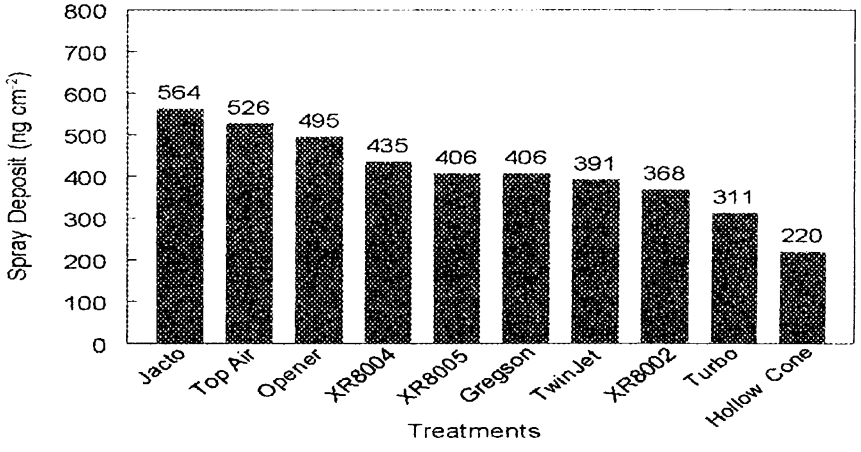

Fig. 1. Middle canopy spray retention from Asian Soybean Rust deposition experiments.

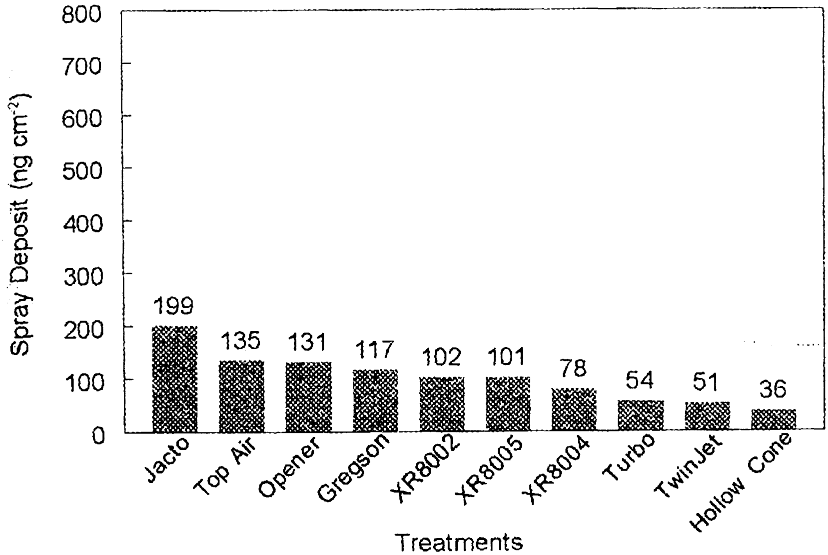

Fig. 2. Bottom canopy spray retention from Asian Soybean Rust deposition experiments.

deeper inside canopies.

Compared to other conventional flat fan pattern nozzles, both TwinJet and Turbo Dual pattern nozzles produced lower deposits at the middle and bottom canopy levels. Droplets from TwinJet and Turbo Dual pattern nozzles had poor penetration capability because these droplets had greater horizontal velocity components. The horizontal movement of droplets consumed kinetic energy and potentially caused droplets to more easily settle in the top leaves of the canopy. To increase the droplet penetration capability, all kinetic energy of a droplet should be used for increasing its vertical velocity. Therefore, with the same application rate, twin fan pattern nozzles could not perform the same spray delivery efficiency as other conventional fan pattern nozzles.

Discussion

SSR management

Many previous experiments have demonstrated the benefits of air-assisted spray delivery but not necessarily for soybeans and in particular situations that require targeting the flowers. While a common practice, high pressure delivery systems alone may not ensure adequate crop protection. Air-assisted and standard flat fan nozzle treatments provided the best overall canopy penetration. High pressure, small droplet treatments made with cone nozzles did not improve canopy penetration. In general, slower travel speeds were superior to higher travel speeds, even for the air-assisted sprayer. Efficacy trials conducted in 1998 using the same operating parameters as described in Table 1 found that thiophanate methyl applied at 1.12 kg a.i. ha^{-1} at the R2 growth stage, significantly increased yields compared to a non treated control plot (Mueller *et al.*, 2002). All treatments also significantly reduced the incidence of Sclerotinia stem rot compared to non- treated controls. Mueller *et al.* (2002) reported no disease or incidence of Sclerotinia stem rot in 2000 and there was no effect of fungicide on yield.

These deposit experiments illustrate that, if direct contact is needed for the fungicide to be effective, more studies are necessary to better match the spray delivery system to the area of the crop being targeted. The parameters to be evaluated include travel speed as well as atomisation, spray volume and delivery techniques. It should be noted that there were many targets found that had little or no detectable deposit above background (no spray) levels. This fact emphasises the difficulty in being able to directly deposit material on the flowers. However, one factor that was not evaluated was possible redistribution of material due to wetting from dew or light rainfall.

ASR management

In general, the spray treatments with air assistance provided higher spray deposition on targets at middle and bottom canopy levels than the treatments with the conventional boom sprayer. The Jacto air-assisted sprayer had the best spray performance of the 10 treatments evaluated. Opening the canopy ahead of the conventional boom sprayer produced deposit results that were very similar to the air assisted spray treatments and were better than other treatments with the boom sprayer. TwinJet, Turbo Dual pattern and hollow cone nozzles produced lower spray performances than conventional flat fan nozzles. There was no difference in deposition on targets inside canopies among fine, medium and coarse spray, flat fan nozzle treatments. Future questions to be answered following this research should be how much fungicide inside canopies could be enough to control the soybean rust disease.

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Footnotes

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