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Nozzle type effect on soybean canopy penetration

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Abstract. *A spray track was designed and built to conduct replicated laboratory and field studies to compare different nozzle configurations on the ability of each to achieve lower canopy spray coverage. The purpose was to determine which nozzles might be more affective in preventing or controlling Asian Soybean Rust. Twenty nozzle types were compared in the lab and twelve nozzle types were compared in the field trials. All comparisons were at 187 L ha*$^{-1}$ *and at a spraying speed of 16 KPH. Orifice size and operating spray pressure for each nozzle was adjusted to maintain the desired spray droplet size (200-300 microns VMD) at the calibrated flow rate of 2.5 LPM (187 L/Ha at 16 KPH). A tank mix solution of water and non-ionic surfactant was used for each comparison to simulate a field spraying scenario. For the field trials a fungicide was added to the solution to further simulate a field spraying scenario. Water Sensitive Paper and DropletScan™ was used to measure and compare VMD, percent area coverage (PAC), and number of droplets per square centimeter (DPS).*

In the laboratory trial, significant differences were found with PAC comparisons ranging from 5.1 to 1.6 percent. The TT11006 sprayed at 344 kPa had the most coverage. Significant differences were also found with number of D/SC with the TT11004 at 655 kPa the highest (145.5). In the field trials, significant differences were found with percent area coverage comparisons ranging from 10 to 6 percent. The TT11005 sprayed at 517 kPa had the most coverage. Significant differences were also found with number of D/SC with the TT11004 at 655 kPa the highest (43). In both experiments the single nozzle designs on average provided more coverage than the double nozzle designs. Actual measured VMD's for all the nozzle treatments in both experiments were higher than expected. The twin or double nozzle treatments had the smaller VMD's.

Keywords. Nozzle, soybean canopy penetration, coverage, deposition, droplet size, fungicide application.

Introduction

Asian Soybean Rust (*Phakopsora pachyrhizi*), a pest first identified in the United States during the late fall of 2004, has the potential to cause severe damage to the soybean crop across a wide area of the United States. In areas where the pathogen has been present, heavy losses have occurred without treatment. Because of the size of the U.S soybean crop, a large rippling affect through the industry may result. Soybean rust can appear and spread quickly over a large area from the plants early vegetative stages through its later stages. If the disease goes untreated, the plant may become entirely defoliated in 10 to 14 days.

The challenging aspect of combating this disease is the lack of practical experience in making fungicide applications to a soybean crop during the growth stages where this disease may strike. The most critical stages for the disease to affect the yield and quality of the soybean plant have been identified as from the start of the flowering (R1) through pod formation (R4) and fill (R5). During these stages the canopy density is increasing, making it difficult to achieve adequate placement of the fungicide.

Experience with disease control in heavy canopies indicates that getting the spray droplets to penetrate into the canopy would be beneficial to achieve the best coverage and improved efficacy. Uk and Courshee, 1982, found that the foliage density has a major influence on the amount of deposit density within the canopy. Experience would also tell us that when using conventional spray systems, it can be very difficult to achieve adequate coverage into lower parts of heavy crop canopies, which is necessary for maximizing product performance.

Objective

The objective of these experiments was to conduct laboratory and field trials to compare ground sprayer nozzle options for applying fungicides to obtain the most coverage in the lower parts of the soybean canopy.

Materials and Methods

Two separate experiments were conducted in 2005. The first was conducted in a laboratory setting using greenhouse grown soybean plants in May 2005. For this trial the potted soybean plants were arranged in a dense canopy representing a drilled soybean field. At the time of the laboratory trials the soybean plants were 61cm tall and in the growth stage R1 to R2 with an estimated canopy fill of 90-95 percent. The second trial was conducted in a soybean field located at the Ashland Bottoms Agronomy Research Station near Manhattan, Kansas in late summer 2005. In the latter case, the soybean plants were drilled and at the time of the treatments were 46cm tall and in the growth stage R3 to R4. The canopy was estimated at 75% filled. See Table 1 for details. Applications conditions can be found in Table 2.

For both studies 187 L $ha^{-1}$and 16 KPH was selected as the application volume and speed of travel. Using this application scenario and a boom with a 51 cm nozzle spacing, the flow rate required would be 2.5 L/Min. The formula used is

$$\text{Nozzle Flow Rate (LPM)} = \frac{\text{L/ha} \times \text{Km/h} \times \text{Nozzle spacing (cm)}}{60{,}000}$$

Nozzle types used in the laboratory study were selected based on possible choices from selected nozzle manufactures. The field trial nozzle choices were selected after reviewing the results from previous trials conducted in the laboratory. Several nozzles with poor performance were eliminated for the second trail. The orifice size chosen was selected first to meet the flow rate requirements for the L ha^{-1} and KPH (2.5 L/Min), and then the pressure necessary to qualify for the droplet spectra desired. The droplet spectrum of 200-300 VMD microns was selected for these studies and most all nozzle treatments were selected to fit this range. This range matches the ASABE Droplet Standard S-572 classification as a high-fine to mid-medium sized droplets. Nozzle manufacturers' droplet sizing charts were used to fit the nozzles for this study. Kirk, et.al., 2004, reported that fine droplet spectrum spays resulted in greater spray deposition on wheat heads when compared to medium droplet sprays. First twenty and then twelve nozzle types consisting of both single and double orifices were selected to meet the standards for these studies (Table 3).

The spray material used in this study consisted of a mixture of 500 ml of tap water and non-ionic surfactant (NIS) at 5 percent volume/volume. For the field trial, Headline (fungicide) to simulate an actual tank mix, was also added. (Wolf, 2004) found that the addition of deposition aids to tank mix for aerial applications tended to increase spray deposition and also affect droplet size.

A special spray track machine was designed and fabricated to simulate actual field spraying conditions and to facilitate multiple treatments and replications. The spray track has an aluminum bar 7.3 m long with an electric motor and chain driven sprayer boom. The electric motor is equipped with three gears that drive a chain that will propel the sprayer boom on the aluminum bar at 8, 16, and 24 KPH. The electric motor was equipped with a brake to stop the spray boom at the end of track. The system was powered in the field by a field generator. The spray bar is supported in the field on tripods and can be adjusted to different heights. The whole setup can be moved to different locations in the field by sliding the tripod along the ground. The sprayer boom has two nozzles spaced 51cm that are controlled by a solenoid valve which was operated by a battery operated remote control. The pressure for each treatment was created by using a CO_2 cylinder. All the treatment solutions were placed in 500 ml high pressure spray bottles and attached to the spray boom to complete the trials. All treatments were randomly assigned with two replications.

Water sensitive paper (Syngetna, 2002), was placed in the lower canopy to function as collectors for the droplets. A total of six water sensitive papers were placed at a height of 10 cm from ground under the spray and two replications were done for each nozzle treatment. Rods and plastic clothes pins were used to place and position the wsp in the lower canopy.

After all treatments and replications were completed and dried, the collection papers were placed in prelabeled-sealable bags for preservation. Because of the high humidity a desiccant pack was placed in each bag to prevent the papers from absorbing additional water. Data envelopes were used to organize and store the papers until analysis was complete. DropletScan™ (WRK of Arkansas, Lonoke, AR; and WRK of Oklahoma, Stillwater, OK; Devore Systems, Inc., Manhattan, KS) was used to analyze the papers. DropletScan™ has been tested as a reliable source for predicting droplet stain characteristics when compared to other card reading methods (Hoffman 2004).

Statistical analyses of the data were conducted with SAS 9.1 (SAS, 2003). The model used was a General Linear Model (GLM) procedure to analyze the water sensitive paper data by treatment as summarized with DropletScan™ looking at the nozzle comparisons of VMD, percent area coverage, and droplets per square centimeter and the respective interactions. The LS Means for each product were tested and used to report the differences (alpha = 0.10) found for each treatment.

Results and discussion

Nozzle treatments were compared for ability to provide spray coverage into the bottom of a dense soybean canopy. DropletScan™ was used to measure and compare the droplet statistics VMD, percent area coverage (PAC), and Droplets per square centimeter (D/SC). The results of the statistical analysis of the DropletScan™ output for the laboratory treatments are presented in Table 4 with the field treatments reported in Table 5. A good indicator of the ability for a nozzle to get spray material into the soybean canopy is to measure the amount of coverage (PAC) achieved in the lower canopy. Using water sensitive paper (wsp) as a collector, significant differences were found among the compared nozzle treatments in the amount of coverage attained in the bottom of the canopy. For the laboratory treatments, PAC ranged from 5.1 to 1.6 percent with the LSD at 2.29 percent. The best coverage in the lower canopy was attained with the TT11006 sprayed at 344 kPa and the TD XR 11004 at 792 kPa (5.1%). There was no significant difference in the top fifteen nozzle treatments. The top four ranked nozzles for PAC were single nozzle orifice designs. The average PAC for the single nozzle treatments was greater than the PAC for the double nozzle designs (3.75 – 3.11%). Three of the significantly lowest coverage amounts were from double orifice designs.

For the field treatments, PAC ranged from 10 to 6 percent with LSD of 3.58 percent. The best coverage in the lower canopy was attained with the TT 11005 sprayed at 517 kPa (10.0%). The next closest coverage amount was delivered by the ER 8006 at 344 kPa (9.0%). The lowest three nozzles, the TJ Duo TT 11003/narrow angle at 344 kPa (6.7%), TwinJet 11006 at 344 kPa (6.3%), and the TT 11006 at 344 kPa (6.0%) were all significantly less than the TT11005, but not any of the other nozzle treatments.

Another critical indicator of ability to control a disease in the bottom of a soybean canopy might be the number of droplets placed into the target area. DropletScan™ reports the number of droplets counted in the area scanned. Thus, transforming the number of droplets into droplets per square centimeter (D/SC) provides another means of comparing the treatments. Again, there were significant differences found in both experiments. In the laboratory test the TT11004 sprayed at 655 kPa was measured with the highest number of D/SC (145.5). The TT11004, ER80-06 at 344 kPa (136.5), SR110-05 at 517 kPa (127), TwinJet 11006 at 344 kPa (125.5), and the TeeJet Duo XR03 at 344 kPa (116.5) were all significantly higher in D/SC than the remaining treatments. The range in D/SC was 145.5 to 75.5 with the LSD at 37.2. It is also noted that in most cases the treatments with the highest PAC did not necessarily have the highest D/SC.

In the field experiment, the twelve nozzle treatments ranged from 43 D/SC to 12 D/SC with the LSD at 23.25. The TT 11004 at 655 kPa placed the most droplets in the lower canopy (43). The ER 8006 at 344 kPa and the TT 11005 at 517 kPa were next with 40.5 each. The next nozzle at 34 was the Twin-cap TT 11003 at 344 kPa. The venturi TD TT 11004 at 792 kPa and the TT 11006 at 344 kPa with 13 and 12 respectively, were significantly lower than the other ten nozzle treatments.

A third and interesting comparison was found when evaluating the measured VMD and comparing it to the calibrated droplet spectra of 200-300 microns which was based on the nozzle manufacturers' droplet sizing charts and the ASABE S-572 Droplet Spectra Classification system. For the laboratory treatments the actual measured VMD ranged from 434 to 260.5 microns with the LSD at 85.4 microns. In the field treatments the actual measured VMD in the bottom of the canopy for all treatments ranged from 515 to 329 microns with the LSD at 64.3 microns. These numbers were much larger than expected. The results of these findings are supported by the literature (SDTF, 2001) which reported that the additions of surfactants and various chemicals to the tank mix would result in larger droplet spectra. Another factor not accounted for to date in this study was the affect of the droplet spread factor on the DropletScan™ calculations for droplet size. The standard water spread factor coefficients were used to determine the droplet sizes in the results of this study. A spread factor test is planned before further reporting is completed.

Conclusions

Laboratory and field comparisons of nozzles that could be used to apply crop protection fungicides with a conventional ground sprayer were performed. Water sensitive paper (wsp) was placed in the bottom of a dense soybean canopy (lab - 95% and field -75% filled) and was used to collect spray droplets from each nozzle treatment. DropletScan™ software was used to analyze the wsp and determine differences in percent area coverage (PAC), number of droplets per square centimeter (D/SC), and VMD.

Treatments were designed to compare all the nozzle types at 187 L $ha^{-1}$and 16 KPH. The orifice size and pressures were adjusted to calibrate each treatment to meet the 200 to 300 VMD micron droplet spectra goal (high fine to mid medium). The TT 11006 at 344 kPa (coarse) and the TT 11005 at 517 kPa (medium to coarse) were the exceptions. All other treatments were considered medium based on the ASABE Droplet Spectra Classification (DCS) S-572 system. The Twinjet 11006 at 344 kPa was borderline medium to fine on the DCS system on the other end of the spectra.

The amount of coverage attained in the lower canopy ranged from 5.1 to 1.6 percent in the laboratory tests and from 10 to 6 percent in the field tests. A difference in coverage between the two experiments is probably attributed to the nearly 20 percent higher canopy density used in the laboratory treatments. Previous research would support canopy density is a major factor in controlling the amount of penetration into the lower portions. In both studies, on average, the single nozzle designs placed more coverage into the bottom of the canopy when compared to the double nozzle designs. The double nozzles were expected to provide better lower canopy coverage. Another interesting finding was that the venturi designs at higher pressures did not perform nearly as well as the conventional nozzles at the lower pressures.

Another droplet characteristic to evaluate for evidence of good canopy penetration is number of droplets per square centimeter (D/SC). For this comparison, the range in performance for the different treatments was considerable. In the laboratory treatments, the TT11004 was the top performer at 145.5 D/SC. This was significantly better than the bottom 15 rated comparisons. Of the top five nozzle treatments the TwinJet 11006 and the TeeJet Duo XR03 were the only double nozzle types not significantly different from the top three single nozzle types. For the field treatments there were no significant differences in the top ten nozzles. As in the laboratory experiment, the top nozzle treatment was the TT 11004. In the field treatments the top three for coverage amount were also found to provide the highest number of droplets though not in the same order. This was not the case in the laboratory treatments though the ER 80-06 and the TT11004 were near the top in both comparisons. As with the PAC data, there does not appear to be an advantage for using the twin or double nozzle configurations, though the differences are not as great.

As was expected the addition of a surfactant and fungicide into the spray mixture increased the size of the spray droplets. What was not learned from this study is whether the increased droplet size above the calibrated DSC will have an affect on controlling Asian Soybean Rust. The answer to that concern can only be determined when similar trials are conducted in the presence of Asian Soybean Rust.

Another observation when evaluating the VMD considerations in these studies was that the twin and double nozzle configurations made it easier to match the calibrated DSC requirements. By using two smaller orifices, a smaller dropsize was predicted and supported with the data. However, that did not necessarily improve the coverage or the number of droplets as might have been expected.

Even though differences were minimal for most treatments, the strategy to use twin or double nozzle configurations for improved lower canopy penetration is not supported by the data in these studies. Therefore, it may not be necessary to outfit spray systems with nozzles other than the conventional turbo and extended range nozzle types. These conventional nozzle systems performed well provided that smaller orifice sizes and higher pressures were selected. The data supports that in addition to calibrating for the increased L ha^{-1} recommendations for fungicide applications, an additional step to calibrate for the proper DCS is essential. This extra calibration step is not a common practice, but when done will typically results in a smaller orifice used at a higher pressure. For example, in this study the TT 11006 at 344 kPa, the TT 11005 at 517 kPa, and the TT 11004 at 655 kPa all provided the same application volume but a different droplet spectra resulting in different amounts of coverage in the lower canopy.

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Tables

Table 1. Experiment details.

	Laboratory treatments	Field treatments
Target GPA[1]	187 L/Ha^{-1}	187 L/Ha^{-1}
Application Speed	16 KPH	16 KPH
Target Swath	1 m	1 m
Boom Height	0.6 m	0.6 m
Nozzle Type	20 configurations	12 configurations
Spray Solution	Tap water and NIS	Tap Water, NIS, Headline
Time	8:30 AM	2:15 PM
Duration	3 hours 30 minutes	3 hours
Soybean Plant Height	61 CM	46 cm
Soybean Growth Stage	R1 – R2	R3 – R4
Soybean Row Spacing	Pots arranged in Drilled	Drilled
Canopy Condition	90 -95% filled	75% filled

[1] All applications were made with a spray track machine designed for this experiment.

Table 2. Application conditions.

Location	Date	Temperature	Relative Humidity	Wind Direction	Wind Speed
Laboratory	5/19/05	29° C	60%	No wind	No wind
Ashland	9/7/06	26° C	40%	200° magnetic[1]	4.5 KPH

[1] Application direction was 180° magnetic

Table 3. Treatment, nozzle, pressure, droplet spectra classification, and tank mix solution.

Treatment	Lab Nozzle Treatments[1]	Field Nozzle Treatments[2]	kPa	Droplet Spectra Classification/DSC[3]
1	XR 11006	XR11006	344	Medium
2	TT 11006	TT11006	344	Coarse
3	TT 11005	TT11005	517	Coarse/Medium
4	TT 11004	TT11004	655	Medium
5	TD XR 11004	TD XR 11004	792	Medium
6	TD TT 11004	TD TT 11004	792	Medium
7	TD XL 11004	X	792	Medium
8	SR 110-05	X	517	Medium
9	SR 110-06	SR 110-06	344	Fine/Medium
10	ER 80-06	ER 80-06	344	Medium
11	TwinCap TT 11003[4]	TwinCap TT03[4]	344	Medium
12	TwinCap TT 11004[4]	X	186	Medium
13	TwinJet 06[4]	TwinJet 06[4]	344	Medium
14	TJ Duo TT 03-wide[4]	X	344	Medium
15	TJ Duo TT 03-Narrow[4]	TJ Duo TT03-Narrow[4]	344	Medium
16	TeeJet Duo XR 03[4]	X	344	Medium
17	AirMix TF05[4]	Airmix TF 05[4]	517	Medium
18	TD TF04[4]	X	792	Medium
19	SR 110-03[4]	X	344	Medium
20	MR 110-025[4]	X	517	Medium

[1] All treatments used a tank mix solution of tap water and non-ionic surfactant.

[2] All treatments used a tank mix solution of tap water, non-ionic surfactant, and Headline.

[3] Based on the ASABE S-572 Droplet Spectra Classification System and nozzle manufacturers' charts/suggestions.

[4] Twin or double orifice nozzle configurations.

Table 4. Laboratory treatment means for VMD, Percent Area Coverage, and Droplets per Square Centimeter.

Treatment[1]	Nozzle	VMD	% Area Coverage	Droplets/sq cm
1	XR 11006	365^{abcd}	1.9^{cd}	83de
2	TT 11006	403^{ab}	5.1^{a}	100^{bcde}
3	TT 11005	400^{ab}	2.6^{bcd}	84.5^{de}
4	TT 11004	342.5^{cde}	4.2^{ab}	145.5^{a}
5	TD XR 11004	367.5^{abcd}	5.1^{a}	106^{bcde}
6	TD TT 11004	402.5^{ab}	3.5^{abcd}	81d^{e}
7	TD XL 11004	434^{a}	3.4^{abcd}	81d^{e}
8	SR 110-05	372.5^{abcd}	3.5^{abcd}	127^{abc}
9	SR 110-06	390^{abc}	3.9^{abc}	99.5^{cde}
10	ER 80-06	335^{bcde}	4.3^{ab}	136.5^{ab}
11	TwinCap TT 11003[2]	308.5^{cde}	2.7^{bcd}	96.5^{cde}
12	TwinCap TT 11004[2]	314^{cde}	2.9^{abcd}	96^{cde}
13	TwinJet 06[2]	301.5^{de}	3.5^{abcd}	125.5^{abc}
14	TJ Duo TT 11003-wide[2]	330.5^{bcde}	1.6^{d}	78.5^{de}
15	TJ Duo TT 11003-Narrow[2]	327.5^{bcde}	3.4^{abcd}	87de
16	TeeJet Duo XR 11003[2]	260.5^{e}	2.4^{bcd}	116.5^{abcd}
17	AirMix TF05[2]	351.5^{abcd}	3.7^{abcd}	99^{cde}
18	TD TF04[2]	356.5^{abcd}	4.2^{ab}	85.5^{de}
19	SR 110-03[2]	313.5^{cde}	3.1^{abcd}	105^{bcde}
20	MR 110-025[2]	331^{bcde}	3.6^{abcd}	75.5^{e}
	LSD	85.4	2.29	37.20

Different letters indicate significance at alpha = 0.10.

[1] All treatments used a tank mix solution of tap water and non-ionic surfactant.

[2] Twin or double orifice nozzle configurations.

Table 5. Field treatment means for VMD, Percent Area Coverage, and Droplets per Square Centimeter.

Treatment[1]	Nozzle	VMD	% Area Coverage	Droplets/sq cm
1	XR11006	442.0^{bcd}	8.1^{ab}	31.5^{ab}
2	TT11006	420.0^{cdef}	6.0^{b}	12.0^{b}
3	TT11005	411.5^{cdef}	10.0^{a}	40.5^{a}
4	TT11004	364.5^{efg}	8.5^{ab}	43.0^{a}
5	SR 11006	486.0^{ab}	7.5^{ab}	30.5^{ab}
6	ER 8006	424.5^{bcde}	9.0^{ab}	40.5^{a}
7	TD XR04	472.0^{abc}	7.3^{ab}	30.5^{ab}
8	TD TT04	515.0^{a}	7.9^{ab}	13.0^{b}
9	Twinjet 06[2]	329.0^{g}	6.3^{b}	30.5^{ab}
10	TJ Duo TT03-Narrow[2]	371.5^{efg}	6.4^{b}	26.0^{ab}
11	Airmix TF 05[2]	406.5^{efd}	7.1^{ab}	26.5^{ab}
12	TwinCap TT03[2]	356.0^{fg}	6.7^{ab}	34.0^{ab}
	LSD	64.3	3.58	23.25

Different letters indicate significance at alpha = 0.10.

[1] All treatments used a tank mix solution of tap water, non-ionic surfactant, and headline.

[2] Twin or double orifice nozzle configurations.