Optimizing fungicide applications for management of Sclerotinia in soybeans

Principal investigator:
Michael Wunsch, Ph.D. / plant pathologist, NDSU Carrington Research Extension Center
PO Box 219 / 663 Hwy. 281 N. / Carrington, ND 58421-0219
701.652.2951 office / 701.652.2055 fax / michael.wunsch@ndsu.edu
Co-investigator:
Kelly Cooper / agronomist, NDSU Robert Titus Research Farm, Oakes, ND

Introduction

Management of white mold, caused by the fungal pathogen *Sclerotinia sclerotiorum,* in soybeans is constrained by difficulties achieving satisfactory fungicide deposition to the lower canopy where most infections begin. Most white mold infections are initiated on dead blossoms on the lower half to lowest quarter of the main stem, and it is difficult to achieve satisfactory fungicide deposition to this target at the R2 to R4 growth stages when soybeans are most susceptible to Sclerotinia. Fungicide coverage is optimized with spray nozzles that deliver small droplets, but small droplets lack the velocity to efficiently penetrate dense canopies. Fungicide deposition to the lower canopy is typically optimized with medium-size droplets that have velocity to penetrate the canopy but still confer acceptable coverage (Derksen 2008). Further gains in fungicide coverage can be made by utilizing a canopy opener (Derksen 2008) or drop nozzles (Rüegg et al. 2006; Rüegg and Total 2013) that facilitate the delivery of fungicides directly into the lower canopy. Delivering fungicides with drop nozzles facilitates pesticide deposition in the interior of the canopy and has been shown to improve disease and insect control in vegetable production in Europe (Rüegg et al. 2006; Rüegg and Total 2013).

This is the first study to quantify the impact of spray droplet size on the performance of fungicides against Sclerotinia in soybeans, and it is the first study to evaluate the delivery of fungicides through drop nozzles for management of this disease. Fungicide application technology research has been conducted in soybeans targeting rust (Derksen 2008), but fungicide deposition patterns required for successful control of rust are different from the fungicide deposition patterns required for successful control of Sclerotinia: Control of rust requires good fungicide deposition to leaves in the interior of the canopy, while control of Sclerotinia requires good fungicide deposition to dead blossoms on stems in the lower canopy. The impact of nozzle spray patterns on Sclerotinia control in canola has been assessed (Kutcher and Wolf 2006), but differences in crop architecture make it difficult to translate those results to soybeans.

The objectives of this project were to (1) quantify the impact of fungicide spray droplet size on white mold control across multiple soybean varieties differing in canopy characteristics; (2) quantify the consistency of the response to fungicide spray droplet size across two nozzle manufacturers (TeeJet and Wilger); and (3) quantify the return to applying fungicides through drop nozzles (versus boom-mounted nozzles) across multiple fungicides commonly used for white mold. Field trials were conducted in Carrington and Oakes, ND on land with a previous history of white mold, with disease pressure facilitated through supplemental overhead irrigation.

Methods

Field studies were conducted quantifying the impact of spray droplet size with TeeJet nozzles (hereafter 'TeeJet droplet size study') or Wilger nozzles (hereafter 'Wilger droplet size study') and evaluating fungicide efficacy when fungicides were applied once or twice with either boom-mounted nozzles or drop nozzles (hereafter 'application methods study'). The study application methods study was only conducted in Carrington; the other studies were conducted in Carrington and in Oakes.

Planting was conducted May 12-18: Studies evaluating the impact of fungicide droplet size were planted May 11 (TeeJet and Wilger nozzle studies, Oakes), May 15 (TeeJet nozzle study, Carrington), and May 18 (Wilger nozzle study, Carrington), and the study evaluating the impact of fungicide application method and application frequency on the comparative efficacy of fungicides was planted May 15. Testing was conducted on four soybean varieties in Carrington and two varieties in Oakes; row spacing was 21 inches, and seeding rate was 165,000 pure live seeds/ac. Treatment plots consisted of three rows, 20 feet (Carrington droplet size studies), 25 feet (Oakes droplet size studies) or 30 feet long (Carrington fungicide application methods study) at seeding.

The application methods study was established as a completely randomized complete block design with a split-split plot arrangement with main factor = fungicide application method (drop nozzle or boom-mounted nozzle), sub-factor = fungicide application frequency (once or twice), and sub-sub-factor = fungicide treatment and seven replicates. The droplet size studies were established as a randomized complete block with 16 replicates (TeeJet droplet size study, Oakes), 13 replicates (TeeJet droplet size study, Carrington), 15 replicates (Wilger droplet size study, Oakes), and 12 replicates (Wilger droplet size study, Carrington).

All soybeans were seeded with a granular Rhizobium inoculant applied in-furrow with the seed, and supplemental fertilization was applied as needed on the basis of soil tests. Weeds were managed with registered pre-emergence herbicides applied on the basis of previous weed history and with post-emergence herbicides applied on the basis of the weeds present. Supplemental hand weeding was conducted to eradicate any weeds that escaped herbicides. In Oakes, supplemental irrigation was delivered through a linear overhead irrigation system as needed to optimize yield potential, with 0.75 inches of water delivered each time the crop was irrigated; to facilitate white mold pressure during the R2 to R4 growth stages, each irrigation event was supplemented with a second application of 0.25 inches of water a day after the first application. In Carrington, supplemental irrigation was delivered through micro-sprinklers with a 20-foot radius established on a 20-foot offset grid. Irrigation commenced at the R1 growth stage and continued through the R5 growth stage, with irrigation scheduled as needed to keep the soil profile moist in the top inch of soil.

Fungicides were applied with a tractor-mounted, PTO-driven spray equipped with a pulse-width modulation system (Capstan AG; Topeka, KS). The boom was equipped with five nozzles, each 20 inches apart, with the first and last nozzles centered over the edges of the treatment plots. Boom height was set in accordance with the manufacturer's recommendations: 20 inches above the canopy for 110-degree nozzles manufactured by TeeJet (TeeJet Technologies, Spraying Systems Company; Glendale Heights, IL), and 19 inches above the canopy for 110-degree nozzles manufactured by Wilger (Wilger Inc., Lexington, TN).

Fungicides were applied in the droplet size studies at the early to full R2 growth stage (75 to 100% of plants at R2) on July 7 (TeeJet and Wilger nozzles, Oakes), July 10 (TeeJet nozzles, Carrington), and July 14 (Wilger nozzles, Carrington). In the studies conducted with Wilger nozzles, the fungicide Endura was applied at 5.5 oz/ac at a 6.0 mph driving speed with ER110-04 Combo Jet flat-fan nozzles at 50 psi (fine droplets), SR110-04 nozzles at 50 psi (medium droplets), MR110-04 nozzles at 50 psi (coarse droplets), and DR110-04 nozzles at 50 psi (very coarse droplets). In the studies conducted with TeeJet nozzles, the fungicide application rate, driving speed, and nozzles differed for the Oakes and Carrington study locations (Table 1).

Table 1. Driving speed, fungicide application rate, nozzles, and application pressures utilized in the studies evaluating the impact of fungicide droplet size on management of white mold in soybeans.

	2017 Carrington	**2018 Carrington & Oakes**	**2019 Carrington & Oakes**	**2020 Carrington**	**2020 Oakes**
	Fungicide applied:				
	Endura at 5.5 oz/ac	Endura at 5.5 oz/ac	Endura at 5.5 oz/ac	Endura at 8.0 oz/ac	Endura at 5.5 oz/ac
	Driving speed:				
	4.0 mph	6.7 mph	8.9 mph	10.5 mph	6.0 mph
	Nozzles and application pressures utilized to achieve the target droplet size spectrum				
Fine droplets	XR8004, 60 psi	XR8003, 50 psi	XR11004, 50 psi	XR11005, 60 psi	XR11004, 60 psi
Medium-fine	XR8004, 40 psi	XR8004, 40 psi	XR11005, 40 psi	XR11006, 50 psi	XR11005, 40 psi
Medium droplets	XR8006, 60 psi	XR8006, 40 psi	XR11006, 35 psi	XR11006, 35 psi	XR11006, 35 psi
Medium-coarse	not tested	XR8008, 35 psi	XR11008, 40 psi	XR11008, 40 psi	XR11008, 40 psi
Coarse droplets	XR8010, 40 psi	XR8010, 30 psi	XR11010, 30 psi	XR11010, 30 psi	XR11010, 30 psi

In the application methods study, fungicides were applied with boom-mounted nozzles on July 8 when 59% of plants were at the R2 growth stage and canopy closure averaged 81% and July 21 at the late R2/early R3 growth stage when canopy closure averaged 91%. On July 8, applications were made with XR11006 flat-fan nozzles at 35 psi (medium droplets); on July 21, applications were made with XR11010 flat-fan nozzles at 30 psi (coarse droplets). Applications with drop nozzles were made on July 12 when 88% of plants were at the R2 growth stage and canopy closure averaged 82% and on July 22 at the late R2/early R3 growth stage when canopy closure averaged 91%. Applications were made with 360 Undercover drop nozzles (360 Yield Center; Morton, IL) equipped with TJ60-11002 nozzles on the side ports and operated at 40 psi (very fine droplets). All applications across all studies were made with a 15 gal/ac spray volume.

Sclerotinia stem rot incidence and severity were assessed when soybeans were at the R8 to R9 growth stage (beginning maturity to full maturity). Plants were individually assessed for white mold severity using a 0 to 5 scale representing the percentage of the plant impacted by Sclerotinia stem rot, where 0 = 0%, 1 = 1-25%, 2 = 26-50%, 3 = 51-75%, 4 = 76-99%, 5=100% of the plant impacted by white mold. Plant tissue was considered to be impacted by Sclerotinia stem rot if it exhibited symptoms of Sclerotinia and/or exhibited unfilled pods due to one or more Sclerotinia lesions that girdled the stem below the pods. Every plant in the middle rows of each three-row plot was individually assessed for white mold severity.

Studies were harvested October 8 (TeeJet droplet size, Oakes), October 9 (Wilger droplet size), October 19 (TeeJet droplet size, Carrington), November 2 (Wilger droplet size, Carrington), and November 2-3 (application methods). Yields were calculated on the basis of a 5-ft plot width and the measured plot length, and seed moisture was assessed after grain was cleaned. Seed yield and test weight were adjusted from the grain actual moisture to a standard 13% moisture level.

Data were evaluated with analysis of variance. (1) The assumption of constant variance was assessed with Levene's test for homogeneity of variances and visually confirmed by plotting residuals against predicted values. (2) The assumption of normality was assessed the Shapiro-Wilk test and visually confirmed with a normal probability plot. (3) The assumption of additivity of main-factor effects across replicates (no replicate-by-treatment interaction) was evaluated with Tukey's test for nonadditivity. All data met model assumptions. *Combined analyses in studies with a split-plot design*: Combined analyses of treatment effects across fungicide treatments were conducted with replicate and fungicide as main-factor effects and application timing/method as a sub-factor and controlling for replicate by main-factor and main-factor by treatment interactions. F-tests for the combined analysis of the main factor (fungicide) and the sub-factor (application timing & method) were conducted utilizing replicate-by-main-factor interaction for the error term. *Treatment contrasts:* Single-degree-of-freedom contrasts were performed for all pairwise comparisons of treatments; to control the Type I error rate at the level of the experiment, the Tukey multiple comparison procedure was employed. Analyses were implemented in PROC UNIVARIATE and PROC GLM of SAS (version 9.4; SAS Institute, Cary, NC).

Results

Impact of droplet size on fungicide performance

The spray droplet size that optimized fungicide performance against white mold was dependent on soybean canopy closure at fungicide application timing. In studies conducted with TeeJet extended-range flat-fan nozzles, fine droplets optimized fungicide performance when average canopy closure was less than 80%; medium droplets optimized fungicide performance when average canopy closure was 80 to 90%; and coarse droplets optimized fungicide performance when average canopy closure was 90 to 100% **(Figure 1)**. With Wilger nozzles, coarse droplets optimized fungicide performance when the canopy was open, and very coarse droplets were optimal when the canopy was near closure **(Figures 2 and 3)**. The impact of spray droplet size on fungicide performance against white mold relative to soybean canopy closure was consistent across study locations and years.

Fungicide efficacy relative to application method and application frequency

The relative efficacy of the fungicides Topsin, Endura and ProPulse was similar irrespective of application method (drop nozzle versus boom-mounted nozzles) and application frequency (**Table 2**). The fungicide Topsin was tested with and without adjuvants, and the adjuvant ‘Preference’ had no impact on the efficacy of Topsin. When the organosilicon adjuvant ‘Silkin’ was added to Topsin, a reduction in yield was observed when fungicides were applied once with boom-mounted nozzles but not when fungicides were applied twice or were applied with drop nozzles. The use of drop nozzles increased the yield gain from fungicide applications. When a single application was made at the R2 growth stage, the various fungicide treatments conferred an average 0 bu/ac yield gain relative to the non-treated control when applied with standard boom-mounted nozzles and an average 2 bu/ac yield gain when applied with drop nozzles. When two sequential applications were made at R2 and 10-13 days later, the various fungicide treatments conferred an average 2 bu/ac yield gain relative to the non-treated control when applied with standard boom-mounted nozzles and an average 5 bu/ac yield gain when applied with drop nozzles.

Discussion and conclusions:

Fungicide performance against white mold in soybeans was strongly influenced by spray droplet size, with the optimal droplet size contingent on the degree of canopy closure when fungicides were applied.

The impact of fungicide spray droplet size relative to canopy closure has been consistent across soybean varieties, study locations and study years. The droplet size that optimizes fungicide performance against white mold increases as the canopy closure increases, with fungicide performance optimized by utilizing the smallest droplet size that has sufficient velocity to penetrate the canopy.

The optimal droplet size at a given degree of canopy closure differs by nozzle manufacturer. In applications made with extended-range TeeJet flat-fan nozzles, fine to medium droplets optimized white mold management when the canopy was very open (average < 75% canopy closure when fungicides were applied). Medium droplets were optimal when the canopy was open (average 80-89% closure), and coarse droplets were optimal when the canopy was at or near closure. With Wilger Combo-Jet flat-fan nozzles, coarse droplets were optimal when the canopy was open, and very coarse droplets were optimal when the canopy was at or near closure. The droplet size categories utilized in these studies are based on the ratings provided by the nozzle manufacturer, not the measured droplet output, and the differences in optimal droplet size may have been due either to the nozzles or to differences in how each manufacturer defines a fine, medium, coarse, or very coarse droplet spectrum. Characterization of the droplet size spectrum emitted by the combinations of nozzles and pressures tested in these droplet size studies is planned.

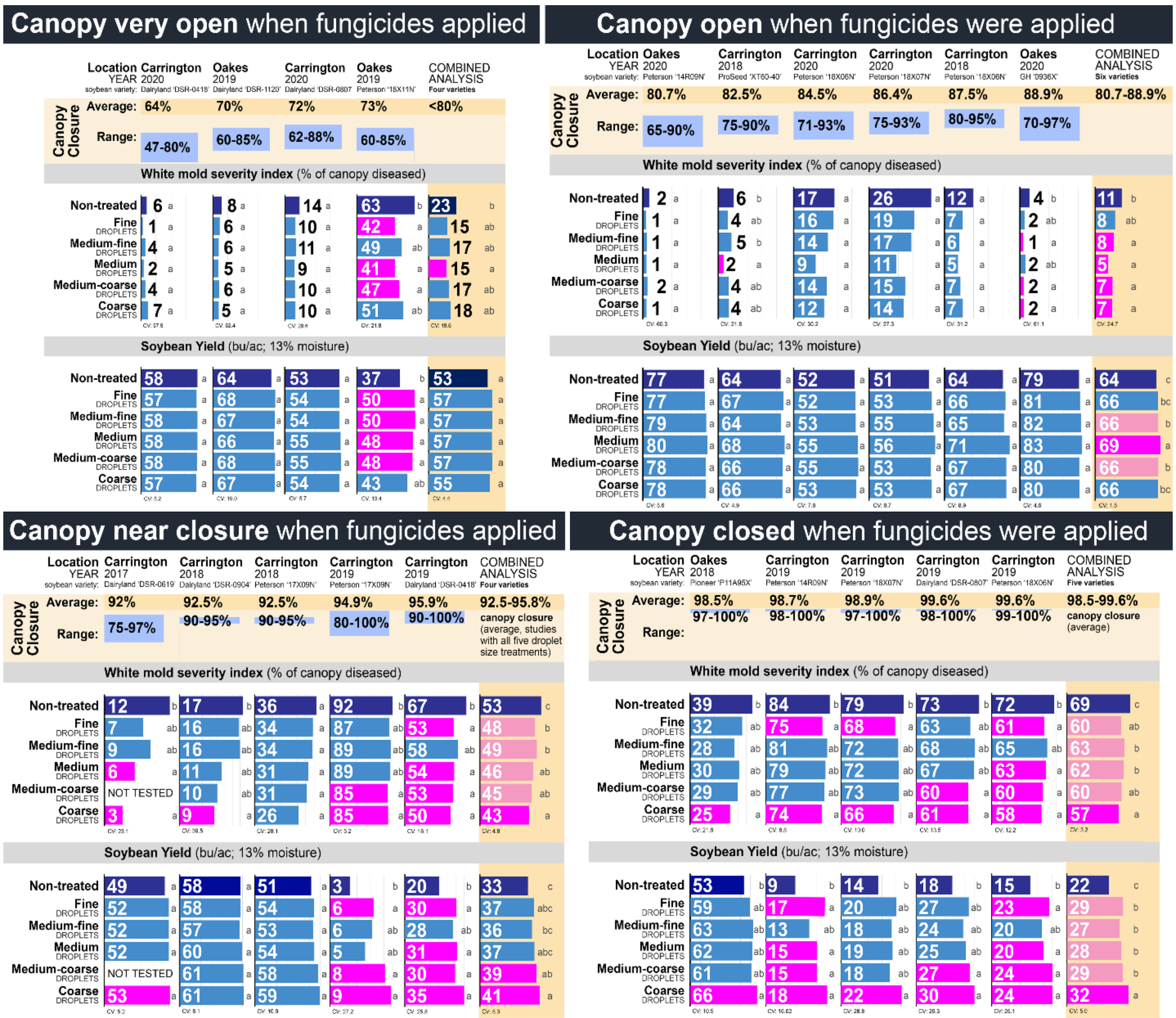
The results indicate that the yield response to fungicide applications targeting white mold in soybeans can be nearly doubled when droplet size is calibrated relative to nozzle manufacturer and soybean canopy closure. The droplet size spectrum considered ‘fine’, ‘medium’, ‘coarse’, etc. differs by nozzle manufacturer. For white mold management in soybeans, droplets considered ‘medium’ by TeeJet performed similarly to droplets considered ‘coarse’ by Wilger, and droplets considered ‘coarse’ by TeeJet performed similarly to droplets considered ‘very coarse’ by Wilger. For both manufacturers, the droplet size that optimizes white mold management increases as soybean canopy closure increases. Smaller droplets optimize fungicide coverage but lack the velocity to penetrate a soybean canopy that is at or near closure.

Applying fungicides through drop nozzles resulted in more consistent white mold control across all fungicide chemistries evaluated, particularly when two sequential fungicide applications were made at the R2 and R3 growth stages. The results closely parallel findings from field trials conducted in 2017, 2018 and 2019.

The return on investment of calibrating fungicide spray droplet size relative to canopy characteristics is very high: The cost of optimizing droplet size is low, limited only to purchasing a set of appropriate nozzles and applying at the correct pressure. This study suggests that further gains in fungicide performance can be achieved by delivering fungicides through drop nozzles, but the cost of implementing this strategy is higher due to the cost of purchasing and installing drop nozzles and the increased time required to make applications. Fungicide applications made through drop nozzles must be made a slower driving speed, and, due to the weight of the ‘360 Undercover’ drop nozzles tested in this study, use of this drop nozzle limits the width that can be sprayed with every pass of the sprayer, thereby furthering increasing the time required to apply fungicides. The use of drop nozzles is most likely to provide a return on investment when the risk of white mold is high.

Literature cited: **Derksen et al. 2008**. Transactions of the American Society of Agricultural and Biological Engineers 51:1529-1537. | **Kutcher and Wolf 2006**. Crop Protection: 640-646. | **Rüegg et al. 2006**. Outlooks on Pest Management 17:80-84. | **Rüegg and Total 2013**. Dropleg – Application technique for better targeted sprays in row crops. Agroscope; Swiss Confederation Federal Office of Agriculture.

Figure 1. Impact of spray droplet size and soybean canopy closure on efficacy of the fungicide Endura applied once at the R2 growth stage with TeeJet extended-range flat-fan nozzles. Pulse width was modified as needed to maintain a 15 gal/ac spray volume and 10.5 mph (4 studies), 8.9 mph (8 studies), 6.7 mph (5 studies), 6.0 mph (2 studies) or 4.0 mph (1 study) driving speed. Treatment averages followed by different letters are significantly different ($P < 0.05$).



Fungicide: Endura 70WG 5.5 oz/ac except studies in Carrington in 2020, when 8.0 oz/ac was applied **Application timing:** 100% of plants at R2 growth stage **Spray volume:** 15 gal/ac

Row spacing: 21 inches **Seeding rate:** 165,000 pure live seeds/ac **Driving speed:** 10.5 mph (Carrington, 2020); 6.0 mph (Oakes, 2020); 8.9 mph (2019); 6.7 mph (2018); 4.0 mph (2017)

Nozzles (2017): XR8004, 60 psi (fine); XR8004, 40 psi (medium-fine); XR8006, 60 psi (medium); XR8010, 40 psi (coarse)

Nozzles (2018): XR8003, 50 psi (fine); XR8004, 40 psi (medium-fine); XR8006, 40 psi (medium); XR8008, 35 psi (medium-coarse); XR8010, 30 psi (coarse)

Nozzles (Carrington, 2019; Oakes, 2019 and 2020): XR11004, 50 psi (fine); XR11005, 40 psi (med.-fine); XR11006, 35 psi (medium); XR11008, 40 psi (med.-coarse); XR11010, 30 psi (coarse)

Nozzles (Carrington 2020): XR11005, 60 psi (fine); XR11006, 50 psi (medium-fine); XR11006, 35 psi (medium); XR11008, 40 psi (medium-coarse); XR11010, 30 psi (coarse)

Figure 2. Impact of spray droplet size on efficacy of the fungicide Endura (5.5 oz/ac) applied once at the R2 growth stage to soybeans with an open canopy using Wilger Combo-Jet flat-fan nozzles. Pulse width was modified as needed to maintain a 15 gal/ac spray volume and 8.9 mph (2 studies) or 6.0 mph (3 studies) driving speed. Treatment averages followed by different letters are significantly different ($P < 0.05$).

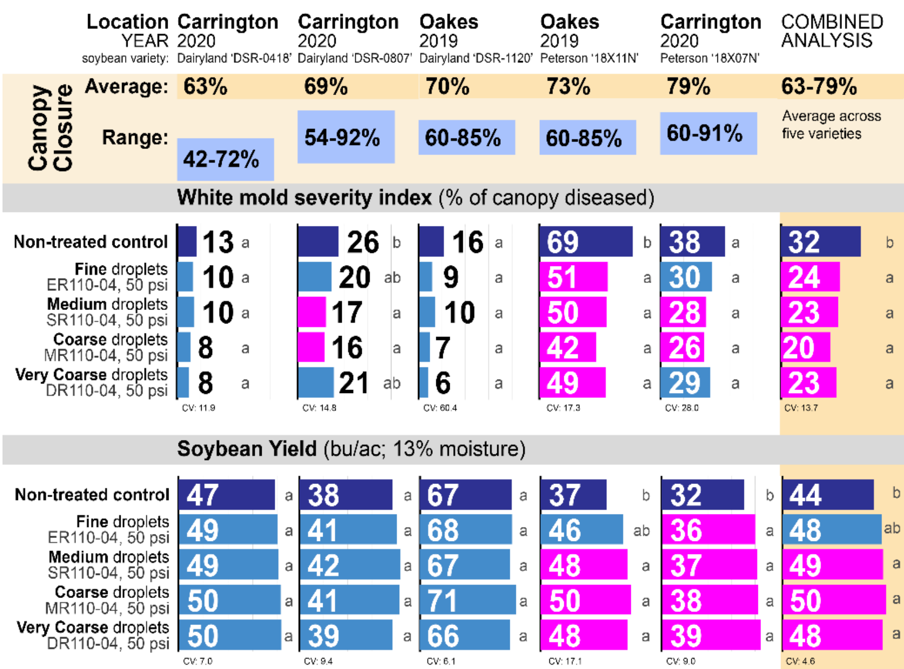


Figure 3. Impact of spray droplet size on efficacy of the fungicide Endura (5.5 oz/ac) applied once at the R2 growth stage to soybeans at or near canopy closure using Wilger Combo-Jet flat-fan nozzles. Pulse width was modified as needed to maintain a 15 gal/ac spray volume and 8.9 mph driving speed. Treatment averages followed by different letters are significantly different ($P < 0.05$).

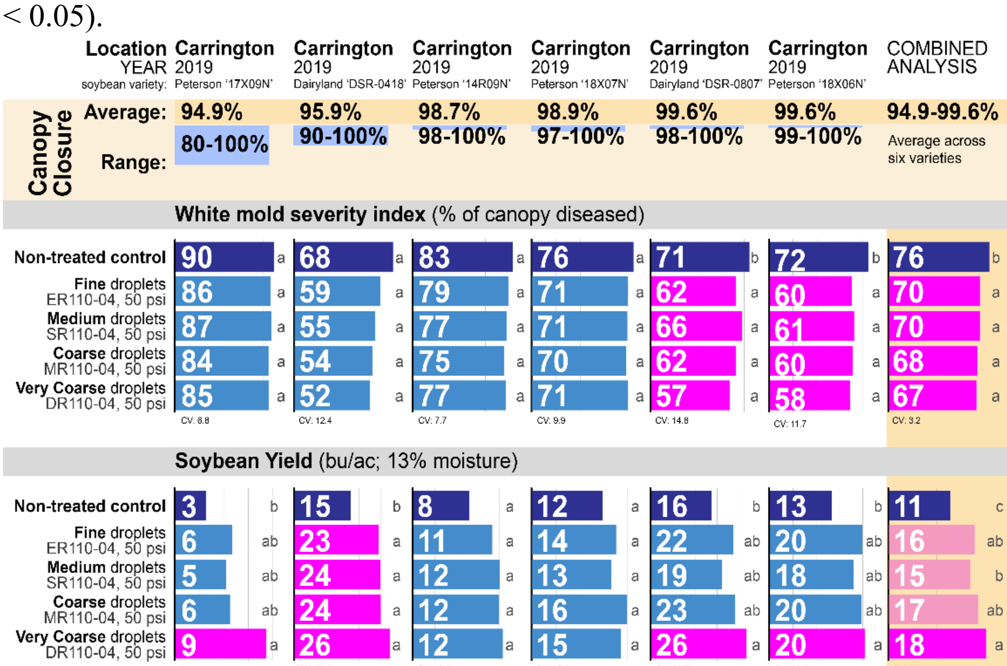


Table 2. Comparative efficacy of one versus two applications of fungicides targeting white mold and delivered via standard boom-mounted nozzles or with '360 Undercover' (360 Yield Center; Morton, IL) drop nozzles.

		WHITE MOLD (% of canopy, R8 growth stage)			
		Boom-mounted nozzles		**Drop nozzles**	
		1 application	2 applications	1 application	2 applications
1	Non-treated control	**13** a*‡	**10** a*‡	**16** a*‡	**13** b*‡
2	Topsin 4.5FL @ 20 fl oz/ac	**13** a	**8** a	**9** a	**5** ab
3	Topsin 4.5FL @ 20 fl oz/ac + Preference @ 0.25% v/v	**14** a	**16** a	**13** a	**4** ab
4	Topsin 4.5FL @ 20 fl oz/ac + Silkin @ 0.25% v/v	**23** a	**8** a	**12** a	**4** a
5	Endura @ 8.0 oz/ac	**10** a	**4** a	**11** a	**5** ab
6	Endura @ 5.5 oz/ac	**19** a	**7** a	**8** a	**4** ab
7	ProPulse @ 8.0 fl oz/ac	**14** a	**9** a	**6** a	**6** ab
8	ProPulse @ 6.0 fl oz/ac	**15** a	**8** a	**7** a	**3** a
	F:	0.96	1.62	0.84	2.62
	P>F:	0.4755	0.1553	0.5606	0.0249
	CV:	25.3	38.9	42.6	49.9
		YIELD (bushels/acre, 13% moisture)			
		Boom-mounted nozzles		**Drop nozzles**	
		1 application	2 applications	1 application	2 applications
1	Non-treated control	**50** ab*	**50** a*	**50** a*	**48** b*
2	Topsin 4.5FL @ 20 fl oz/ac	**53** a	**52** a	**52** a	**52** ab
3	Topsin 4.5FL @ 20 fl oz/ac + Preference @ 0.25% v/v	**50** ab	**47** a	**51** a	**55** a
4	Topsin 4.5FL @ 20 fl oz/ac + Silkin @ 0.25% v/v	**45** b	**53** a	**51** a	**53** a
5	Endura @ 8.0 oz/ac	**53** a	**51** a	**52** a	**57** a
6	Endura @ 5.5 oz/ac	**49** ab	**53** a	**51** a	**54** a
7	ProPulse @ 8.0 fl oz/ac	**50** ab	**53** a	**52** a	**56** a
8	ProPulse @ 6.0 fl oz/ac	**51** a	**51** a	**51** a	**57** a
	F:	4.13	2.07	0.51	8.19
	P>F:	0.0015	0.0681	0.8231	< 0.0001
	CV:	6.5	7.0	6.3	4.9

*** Within-column means followed by different letters are significantly different (***P* < 0.05; Tukey mult. comparison procedure).

‡ To meet model assumptions of normality and/or homoskedasticity, analysis of variance was conducted on data subjected to a systematic natural-log transformation. For ease of interpretation, treatments means are presented for the non-transformed data.