Prospects for using drop nozzles to improve fungicide coverage and control of Sclerotinia head rot

Michael J. Wunsch, Michael Schaefer, Billy Kraft, Jesse Hafner, and Suanne Kallis
North Dakota State University Carrington Research Extension Center

Introduction:

The use of fungicides to control Sclerotinia head rot of sunflowers, caused by the fungal pathogen *Sclerotinia sclerotiorum,* has been constrained by the difficulties of achieving satisfactory fungicide coverage to the front of sunflowers heads with traditional fungicide application methods over the top of the crop canopy. Most Sclerotinia head rot infections begin from the front of the sunflower; traditional fungicide application methods result in the deposition of most of the fungicide on the back of the sunflower head, and the thickness of sunflower heads precludes disease control via translaminar movement of the fungicide through the head tissues. The objective of this project was to evaluate whether fungicide deposition to the front of sunflower heads, Sclerotinia head rot control, and sunflower yield under head rot disease pressure could be improved by applying fungicides through drop nozzles mounted on a high-clearance spray boom.

Summary of methods:

A non-treated control and a traditional fungicide application with boom-mounted flat-fan nozzles were compared to multiple applications made through drop nozzles in which drop nozzle type, spray nozzle type, application pressure, and/or the direction that the tractor was driven were varied. Endura 70WG (boscalid; BASF Corp.) was applied at 8 oz/ac in all fungicide treatments. Testing was conducted on an oilseed hybrid and a confectionary hybrid, and every fungicide treatment was tested against four disease inoculation treatments: non-inoculated and inoculated at a target R5.1-R5.3, R5.4-R5.6, or R5.7-R5.9 growth stage. Fungicide coverage was assessed with water-sensitive spray cards placed on the front of sunflower heads.

Summary of key results:

The application of fungicides through flat-fan nozzles mounted directly to a high-clearance spray boom resulted in zero to very poor fungicide deposition to the front of sunflower heads, and fungicide deposition to the front of sunflower heads was sharply improved with the use of drop nozzles (Figures 1 to 3). Fungicide deposition was optimized with applications at 60 psi made with 110-degree flat-fan nozzles and 80-degree hollow-cone nozzles mounted on the side ports of the '360 Undercover' drop nozzle (360 Yield Center; Morton, IL), and satisfactory fungicide deposition to the front of sunflower heads was maintained with the hollow-cone nozzles irrespective of the direction the tractor was driven. However, no control of Sclerotinia head rot was observed in any treatments on either sunflower hybrid (Tables 1 to 3).

Conclusions:

The excellent fungicide coverage obtained to the front of sunflower heads with applications made through drop nozzles suggests that this application method has the potential to facilitate control of Sclerotinia head rot with sunflowers. However, the lack of disease control observed with the fungicide Endura (boscalid), which has consistently shown efficacy against Sclerotinia diseases caused by *S. sclerotiorum* on other crops, indicates that additional problems must be resolved.

Possible causes for the lack of disease control observed in these field trials include (1) poor efficacy of the fungicide utilized (8 oz/ac Endura 70WG) against Sclerotinia against this target due to the inherent properties of the fungicide and how it moves within the plant, (2) the lack of movement of the fungicide from immature disk flower buds on which spray droplets were deposited to other disk flower buds on which spray droplets were not deposited, (3) non-optimal fungicide application timing, and (4) insufficient residual fungicide translocated from immature green disk flower buds to the susceptible open and senescing disk flowers as bloom progresses.

Future approaches:
Future studies will seek to further improve fungicide deposition with drop nozzles and will evaluate fungicide efficacy and timing utilizing drop nozzles.

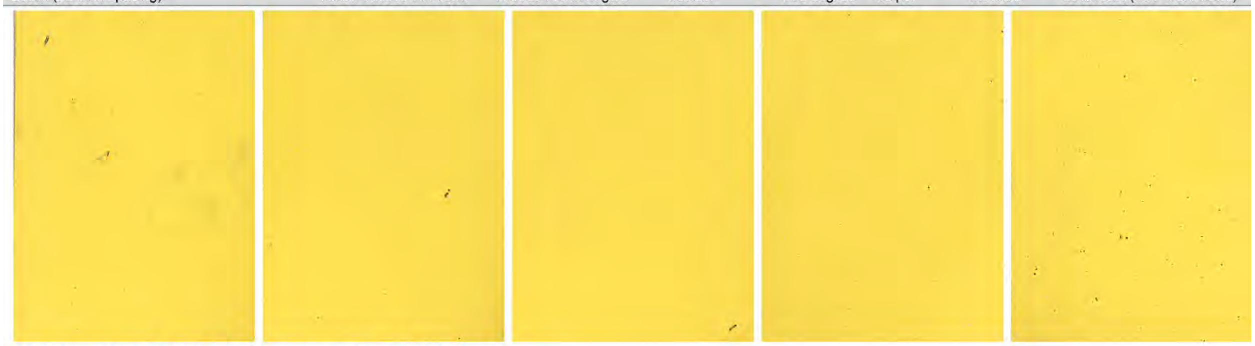
Multiple fungicides will be evaluated at three different application timings using a drop nozzle and spray nozzle configuration that provided excellent coverage to the front of sunflower heads in the field trials conducted in 2015. All fungicides will be applied with a silicone-based adjuvant that facilitates the physical spread of spray droplets on plant surfaces from the point of deposition to neighboring tissues.

Research on fungicide application methods will focus on (1) improving spray deposition to heads of short and tall sunflower plants that did not receive satisfactory fungicide coverage due to their height in the field trials conducted in 2015 and (2) achieving satisfactory spray deposition to the front of heads for Sclerotinia head rot control while concurrently achieving satisfactory spray deposition to foliage and stems for control of other diseases including rust.

Figure 1. Fungicide deposition to the front of sunflower heads; confection hybrid, Carrington, ND (2015). Pictured water-sensitive spray cards that were affixed to the front of sunflower heads; blue denotes areas where spray droplets were deposited.

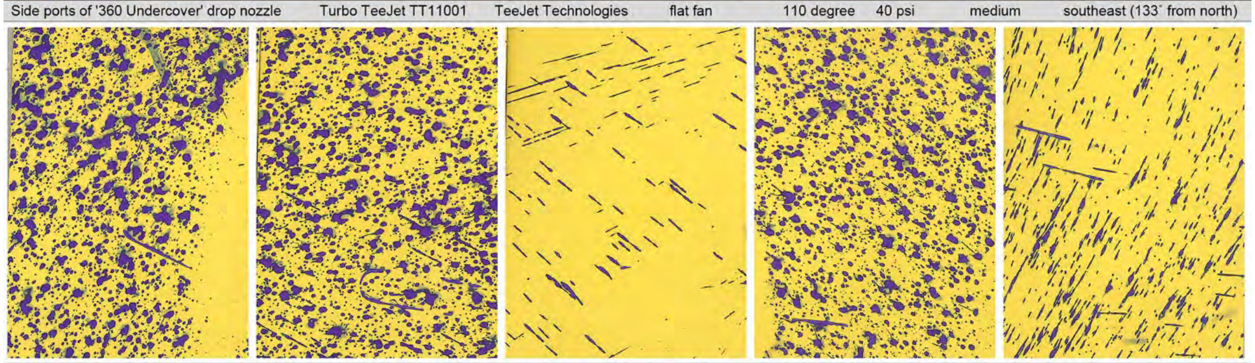
Traditional application method: flat-fan nozzles mounted directly on a high-clearance boom

Nozzle placement	Nozzle	Manufacturer	Spray Pattern	Spray Aı Pressure	Droplet Size	Direction tractor was driven
Boom (20-inch spacing)	Turbo TeeJet TT11001	TeeJet Technologies	flat fan	110 degree 40 psi	medium	southeast (133˚ from north)



'360 Undercover' drop nozzle equipped with flat-fan nozzles

Nozzle placement	Nozzle	Manufacturer	Spray Pattern	Spray Aı Pressure	Droplet Size	Direction tractor was driven
Side ports of '360 Undercover' drop nozzle	Turbo TeeJet TT11001	TeeJet Technologies	flat fan	110 degree 40 psi	medium	southeast (133˚ from north)



'360 Undercover' drop nozzle equipped with flat-fan nozzles; increased application application pressure

Nozzle placement	Nozzle	Manufacturer	Spray Pattern	Spray Aı Pressure	Droplet Size	Direction tractor was driven
Side ports of '360 Undercover' drop nozzle	Turbo TeeJet TT11001	TeeJet Technologies	flat fan	110 degree 60 psi	fine	southeast (133˚ from north)

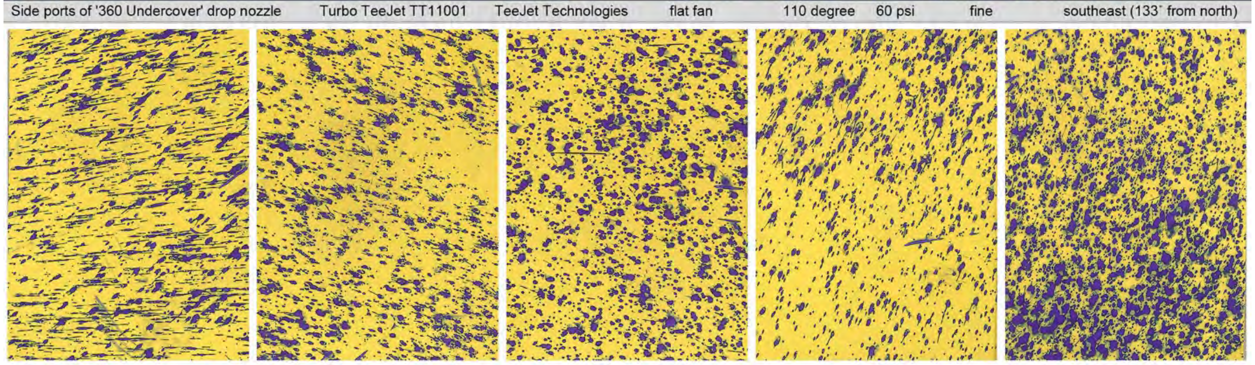


Figure 2. Fungicide deposition to the front of sunflower heads; confection hybrid, Carrington, ND (2015). Pictured water-sensitive spray cards that were affixed to the front of sunflower heads; blue denotes areas where spray droplets were deposited.

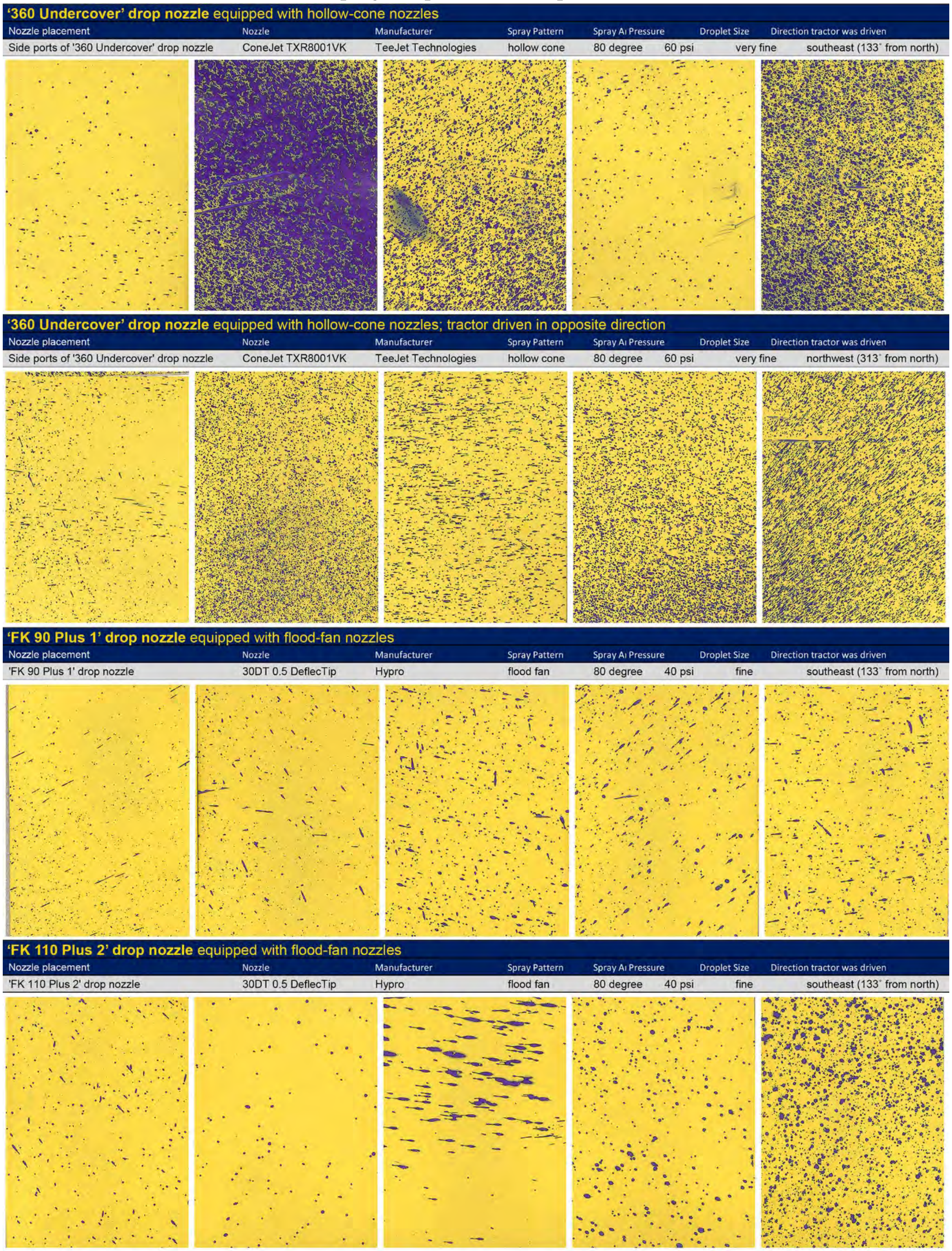
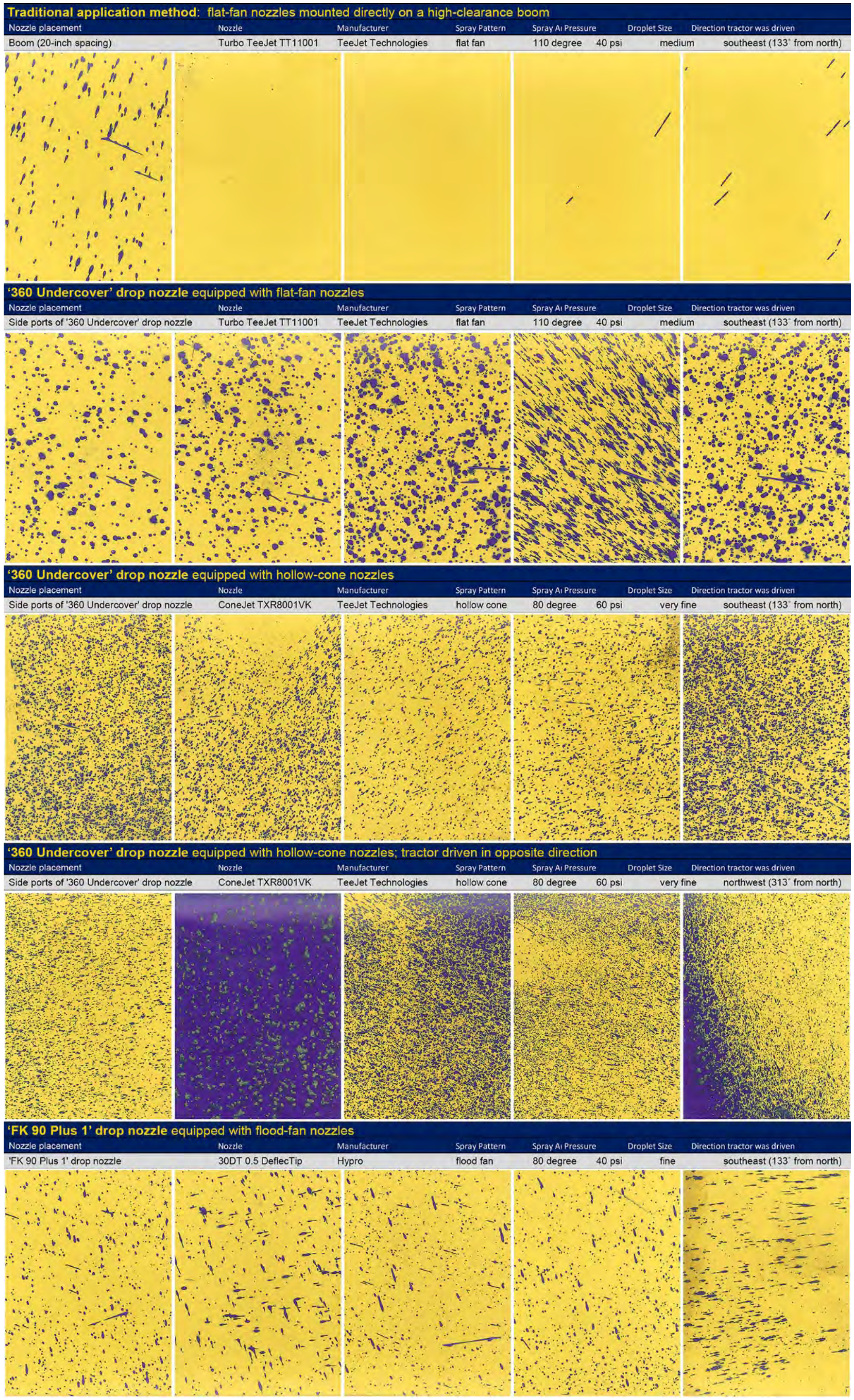


Figure 3.



Fungicide deposition to the front of sunflower heads; oilseed hybrid, Carrington, ND (2015).

Pictured water-sensitive spray cards that were affixed to the front of sunflower heads; blue denotes areas where spray droplets were deposited.

Table 1. Details on fungicide application treatments imposed.

	Treatment Details - Confection Sunflowers							
	Nozzle placement	Nozzle	Manufacturer	Spray Pattern	Spray Angle	Pressure	Droplet Size	Direction tractor was driven
1	Non-treated							
2	Boom (20-inch spacing)	Turbo TeeJet TT11001	TeeJet Technologies	flat fan	110 degree	40 psi	medium	southeast (133° from north)
3	Side ports of '360 Undercover' drop nozzle	Turbo TeeJet TT11001	TeeJet Technologies	flat fan	110 degree	40 psi	medium	southeast (133° from north)
4	Side ports of '360 Undercover' drop nozzle	Turbo TeeJet TT11001	TeeJet Technologies	flat fan	110 degree	60 psi	fine	southeast (133° from north)
5	Side ports of '360 Undercover' drop nozzle	ConeJet TXR8001VK	TeeJet Technologies	hollow cone	80 degree	60 psi	very fine	southeast (133° from north)
6	Side ports of '360 Undercover' drop nozzle	ConeJet TXR8001VK	TeeJet Technologies	hollow cone	80 degree	60 psi	very fine	northwest (313° from north)
7	'FK 90 Plus 1' drop nozzle	30DT 0.5 DeflecTip	Hypro	flood fan	80 degree	40 psi	fine	southeast (133° from north)
8	'FK 110 Plus 2' drop nozzle	30DT 0.5 DeflecTip	Hypro	flood fan	80 degree	40 psi	fine	southeast (133° from north)
	Treatment Details - Oilseed Sunflowers							
	Nozzle placement	Nozzle	Manufacturer	Spray Pattern	Spray Angle	Pressure	Droplet Size	Direction tractor was driven
1	Non-treated							
2	Boom (20-inch spacing)	Turbo TeeJet TT11001	TeeJet Technologies	flat fan	110 degree	40 psi	medium	southeast (133° from north)
3	Side ports of '360 Undercover' drop nozzle	Turbo TeeJet TT11001	TeeJet Technologies	flat fan	110 degree	40 psi	medium	southeast (133° from north)
4	Side ports of '360 Undercover' drop nozzle	ConeJet TXR8001VK	TeeJet Technologies	hollow cone	80 degree	60 psi	very fine	southeast (133° from north)
5	Side ports of '360 Undercover' drop nozzle	ConeJet TXR8001VK	TeeJet Technologies	hollow cone	80 degree	60 psi	very fine	northwest (313° from north)
6	'FK 90 Plus 1' drop nozzle	30DT 0.5 DeflecTip	Hypro	flood fan	80 degree	40 psi	fine	southeast (133° from north)

Table 2.

Sclerotinia head rot control and agronomic outcomes, confection sunflowers – combined analysis across all inoculation treatments; Carrington, ND (2015).

Disease pressure differed across inoculation treatments, but the impact of fungicide application treatments was consistent across all inoculation treatments and the combined results are presented.

	COMBINED ANALYSIS - FUNGICIDE TREATMENT	Sclerotinia Head Rot: Incidence [z]	Severity [y]	Sev. Index [x]	Yield	Test weight	Sclerotia in harvested grain [w]	Sclerotia in cleaned grain [v]
		R8 to R9 growth stage, Sept. 30						
		%	%	%	lbs/ac	lbs/bu	% by weight	% by weight
1	Non-treated	36 a*	98	35 a*	1668 a*	45.4 a*	2.3 a*‡	2.3 a*‡
2	Boom-mounted TT11001 flat-fan nozzles, 40 psi, tractor driven southeast	37 a	99	36 a	1794 a	46.3 a	3.1 a	3.1 a
3	'360 Undercover' drop nozzle, TT11001 flat-fan nozzles on side ports, **40 psi**, tractor driven southeast	37 a	99	37 a	1753 a	46.2 a	2.7 a	2.7 a
4	'360 Undercover' drop nozzle, TT11001 flat-fan nozzles on side ports, **60 psi**, tractor driven southeast	36 a	99	36 a	1719 a	47.3 a	2.6 a	2.6 a
5	'360 Undercover' drop nozzle, TXR8001VK hollow-cone nozzles on side ports, 60 psi, **tractor driven southeast**	39 a	98	39 a	1666 a	46.3 a	3.5 a	3.5 a
6	'360 Undercover' drop nozzle, TXR8001VK hollow-cone nozzles on side ports, 60 psi, **tractor driven northwest**	39 a	99	38 a	1716 a	46.5 a	3.2 a	3.2 a
7	**'FK 90 Plus 1' drop nozzle**, 30DT 0.5 DeflecTip flood-fan nozzles on side ports, 40 psi, tractor driven southeast	41 a	98	40 a	1749 a	44.8 a	3.3 a	3.3 a
8	**'FK 110 Plus 2' drop nozzle**, 30DT 0.5 DeflecTip flood-fan nozzles on side ports, 40 psi, tractor driven southeast	38 a	99	38 a	1744 a	46.5 a	3.1 a	3.1 a
	F:	0.61		0.61	0.59	2.02	0.97	1.46
	P>F:	0.7455		0.7455	0.7608	0.0586	0.4545	0.1888
	CV:	24.9		25.0	14.7	5.1	38.4	58.9
	COMBINED ANALYSIS - INOCULATION TIMING							
	Non-inoculated	2 a*	100	2 a*	2159 a*	22.9 a*	0.3 a*‡	0.2 a*
	TARGET INOCULATION TIMING R5.1-R5.3	38 b	98	37 b	1710 b	22.2 bc	3.2 b	2.3 b
	TARGET INOCULATION TIMING R5.4-R5.6	46 b	98	45 b	1602 b	22.0 b	3.3 b	2.6 b
	TARGET INOCULATION TIMING R5.7-R5.9	66 c	99	65 c	1294 c	21.4 c	5.1 c	4.4 c
	F:	57.92		58.41	35.42	12.30	43.38	24.49
	P>F:	< 0.0001		< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
	CV:	24.9		25.0	14.7	5.1	38.4	58.9

[z] **Sclerotinia head rot incidence:** The percent of plants exhibiting Sclerotinia head rot on Sept. 30 at the R8-R9 growth stage. Every plant in each plot was assessed.

[y] **Sclerotinia head rot severity:** Average Sclerotinia head rot severity among plants exhibiting the disease on Sept. 30 at the R8-R9 growth stage. Every plant in each plot was assessed for the percent of head tissue exhibiting Sclerotinia head rot.

[x] **Sclerotinia head rot severity index:** Average Sclerotinia head rot severity among all plants, including those not exhibiting the disease, on Sept. 30 at the R8-R9 growth stage. Every plant in each plot was assessed for the percent of head tissue exhibiting Sclerotinia head rot.

[w] **Sclerotia in harvested grain:** Percent sclerotia (by weight(in the harvested grain. Assessed by manually separating all sclerotia from a 200-gram subsample of harvested grain from each plot.

[v] **Sclerotia in cleaned grain:** Percent sclerotia (by weight) that could not be mechanically separated on the basis of size. Assessed by manually separating all sclerotia from a 300-gram subsample of grain that had been cleaned by passing it through a shaker equipped with an upper sieve with 30/64 round holes and a lower sieve with 1/16 x 1/2 slotted holes.

‡ To meet model assumptions of normality and homoskedasticity, analysis of variance was conducted on data subjected to a systematic natural-log transformation [ln(x+1) for data sets including values less than 1.0; otherwise, ln(x)]. For ease of interpretation, treatments means are presented for the non-transformed data.

† Disease severity was not analyzed in this treatment due to small sample sizes which precluded a rigorous analysis; in most plots, fewer than 3 plants were diseased.

* Within-column means followed by different, non-overlapping ranges of letters are significantly different ($P < 0.05$; Tukey multiple comparison procedure).

Table 3.

Sclerotinia head rot control and agronomic outcomes, oilseed sunflowers – combined analysis across all inoculation treatments; Carrington, ND (2015).

Disease pressure differed across inoculation treatments, but the impact of fungicide application treatments was consistent across all inoculation treatments and the combined results are presented.

	COMBINED ANALYSIS - FUNGICIDE TREATMENT		Head rot incidence	Head rot severity	Head rot sev. index
			October 14 | R9 growth stage		
			%	%	%
1	Non-treated		29 a*	97 ‡	28 a*
2	Boom-mounted TT11001 flat-fan nozzles, 40 psi, tractor driven southeast		22 a	99	22 a
3	'360 Undercover' drop nozzle, TT11001 flat-fan nozzles on side ports, **40 psi**, tractor driven southeast		27 a	98	27 a
5	'360 Undercover' drop nozzle, TXR8001VK hollow-cone nozzles on side ports, 60 psi, **tractor driven southeast**		28 a	98	28 a
6	'360 Undercover' drop nozzle, TXR8001VK hollow-cone nozzles on side ports, 60 psi, **tractor driven northwest**		25 a	95	24 a
7	**'FK 90 Plus 1' drop nozzle**, 30DT 0.5 DeflecTip flood-fan nozzles on side ports, 40 psi, tractor driven southeast		26 a	94	24 a
		F:	0.81		0.83
		P>F:	0.5451		0.5306
		CV:	42.8		43.1
	COMBINED ANALYSIS - INOCULATION TIMING				
	Non-inoculated		2 a*	97 ‡	2 a*
	TARGET INOCULATION TIMING R5.1-R5.3		24 b	96	23 b
	TARGET INOCULATION TIMING R5.4-R5.6		30 b	96	29 b
	TARGET INOCULATION TIMING R5.7-R5.9		47 c	98	46 c
		F:	35.79		33.44
		P>F:	< 0.0001		< 0.0001
		CV:	42.8		43.1

[z] **Sclerotinia head rot incidence:** The percent of plants exhibiting Sclerotinia head rot on Sept. 30 at the R8-R9 growth stage. Every plant in each plot was assessed.

[y] **Sclerotinia head rot severity:** Average Sclerotinia head rot severity among plants exhibiting the disease on Sept. 30 at the R8-R9 growth stage. Every plant in each plot was assessed for the percent of head tissue exhibiting Sclerotinia head rot.

[x] **Sclerotinia head rot severity index:** Average Sclerotinia head rot severity among all plants, including those not exhibiting the disease, on Sept. 30 at the R8-R9 growth stage. Every plant in each plot was assessed for the percent of head tissue exhibiting Sclerotinia head rot.

[w] **Sclerotia in harvested grain:** Percent sclerotia (by weight(in the harvested grain. Assessed by manually separating all sclerotia from a 200-gram subsample of harvested grain from each plot.

[v] **Sclerotia in cleaned grain:** Percent sclerotia (by weight) that could not be mechanically separated on the basis of size. Assessed by manually separating all sclerotia from a 300-gram subsample of grain that had been cleaned by passing it through a shaker equipped with an upper sieve with 30/64 round holes and a lower sieve with 1/16 x 1/2 slotted holes.

‡ Data did not meet the assumptions of analysis of variance. No systematic transformation could be found that addressed the problem, and the data were not analyzed.

† Disease severity was not analyzed in this treatment due to small sample sizes which precluded a rigorous analysis; in most plots, fewer than 3 plants were diseased.

* Within-column means followed by different, non-overlapping ranges of letters are significantly different ($P < 0.05$; Tukey multiple comparison procedure).

Detailed methods

Location of trials: NDSU Carrington Research Extension Center, Carrington, ND.
GPS coordinates of research trial location: 47.503974, -99.120903 (confection sunflower), 47.503289, -99.121682 (oilseed sunflower)

Agronomics

Previous crop: flax (confection sunflower), field pea (oilseed sunflower)
Tillage: disked in September 2014; cultivated on June 1 and 3, 2015
Soil fertility – trial seeded to confection hybrid: Nitrogen, 39 lb/ac 0-6" from surface and 102 lb/ac 6 to 24" from surface; phosporous, 82 ppm; potassium, 465 ppm; sulfur, 14 lb/ac 0-6" from surface and 48 lb/ac 6-24" from surface; zinc, 2.43 ppm; organic matter, 3.8%; pH, 7.6 at 0-6" from surface and 8.2 at 6-24" from surface; soluble salts, 0.26 mmho/cm 0-6" from surface and 0.36 mmho/cm 6-24" from surface.
Soil fertility – trial seeded to oilseed hybrid: Nitrogen, 46 lb/ac 0-6" from surface and 54 lb/ac 6 to 24" from surface; phosporous, 57 ppm; potassium, 294 ppm; sulfur, 16 lb/ac 0-6" from surface and 42 lb/ac 6-24" from surface; organic matter, 3.2%; pH, 7.6 at 0-6" from surface and 8.2 at 6-24" from surface; soluble salts, 0.36 mmho/cm 0-6" from surface and 0.28 mmho/cm 6-24" from surface.
Supplemental fertilization: No fertilizer was applied.
Maintenance herbicide applications: Sonalan HFP (ethalfluralin, 3 lbs ai/gal; Dow AgroSciences) was applied at 2 pt/ac on June 3 and incorporated the same day. Blanket 4F (sulfentrazone, 4 lbs ai/gal; Tenkoz, Alpharetta GA) was applied at 4.5 fl oz/ac on June 5 and watered in with supplemental irrigation on June 8.

Experimental design

Experimental design: completely randomized split-plot design with inoculation treatment (non-inoculated, inoculated at R5.1-R5.3, inoculated at R5.4-R5.6, and inoculated at R5.7-R5.9) as main factor and application timing and inoculation timing as sub-factor Replicates: 5
Harvested plot size: 5 feet (center-to-center) x 25 feet long. Untreated buffer plots were established between treatment plots.
Row spacing: 30 inches **Rows per plot:** three; two rows were inoculated, assessed for disease, and harvested; one row was used to assess fungicide coverage.

Planting

Confection Hybrid: NuSeed 'Jaguar'
Oilseed Hybrid: Croplan '305 DRM NS'
Planting date: June 4
Seeding rate: 60,000 seeds/ac
Final plant population: 17,400 plants/ac (confection hybrid) and 21,000 plants/ac (oilseed hybrid). The final plant population was established by manually thinning the sunflowers at the V8-V10 growth stage on July 7-9.

Fungicide applications

Drop nozzles: Drop nozzles were spaced 30 inches apart, and the tractor was driven appropriately to center the drop nozzles between the rows The 360 Undercover drop nozzle was manufactured by the 360 Yield Center (Morton, IL); the FK 90 plus 1 and FK 110 plus 2 drop nozzles are manufactured by Kuhn Landmaschinen AG (Dintikon, Switzerland).
Fungicide application timing – confection hybrid: August 11 at 10:30 am - 5:00 pm; temperature = 80-87F, relative humidity = 33-55%, wind speed = 8-10 mph. 82% of sunflowers with open disk flowers; among sunflowers in bloom, an average of 30% of disk flowers were in bloom or already completed bloom.
Fungicide application timing – oilseed hybrid: August 12 at 9:00 am - 12:00 noon; temperature = 77-88F, relative humidity = 57-71%, wind speed = 9-13 mph. approx. 80% of sunflowers with open disk flowers.
Fungicide application details:

- Flat-fan nozzles mounted directly on the boom: TeeJet TurboTee 11001 flat-fan nozzles (Spraying Systems Co.; Glendale Heights, IL) spaced 20 inches apart; 40 psi; 15 gallons of water/acre; 18 inches above the canopy.
- Flat-fan nozzles mounted on '360 Undercover' drop nozzles: TeeJet TurboTee 11001 flat-fan nozzles (Spraying Systems Co.; Glendale Heights, IL) were attached to the side ports of the 360 Undercover drop nozzle (360 Yield Center; Morton, IL); 40 or 60 psi; 15 gallons of water/ac; boom positioned so that nozzles were centered at the average mid-point of the sunflower heads.

- Hollow-cone nozzles mounted on '360 Undercover' drop nozzles: TeeJet TXR8001VK hollow-cone nozzles (Spraying Systems Co.; Glendale Heights, IL) were attached to the side ports of the 360 Undercover drop nozzle (360 Yield Center; Morton, IL); 60 psi; 15 gallons of water/ac; boom positioned so that nozzles were centered at the average mid-point of the sunflower heads.
- Flood-fan nozzles mounted on 'FK 90 plus 1' and 'FK110 plus 2' drop nozzles: 30DT 0.5 DeflecTips with a 80-degree spray angle (Hypro, a subsidiary of Pentair; New Brighton, MN) were mounted on the side ports with the nozzles pointing horizontally into the canopy. Flood nozzles with a 140-degree spray angle were mounted on the bottom ports with the nozzles pointing upward at a 45-degree angle. Applications were made at 40 psi in 15 gal water/ac.

Fungicide deposition to the front of sunflower heads was assessed in three of the five replicates of the experiment using 2 in. x 3 in. TeeJet Water-Sensitive Cards (Spraying Systems Co.; Glendale Heights, IL). A spot was in the interior of the southern row of each 3-row treatment plot (this row was not assessed for disease or yield) was arbitrarily chosen, and the five sequential plants within the row from that spot were utilized to assess spray coverage. On each of the plants, a 3 in. x 5 in. index card placed inside a ziplock bag was secured to the front of the sunflower head with a rubber band to provide a dry, flat surface for mounting the water-sensitive spray card. The spray card was attached to the bagged index card with a paper clip, removed immediately after fungicide applications, and stored in a paper bag placed within a ziplock bag with dessicant. The spray cards were scanned at 600 pixels per inch resolution.

Disease establishment and disease assessment

Inoculation methods: Inoculations were conducted over multiple days such that every head was at R5.1 to R5.3 (10 to 30% of the disk flowers blooming or already bloomed), R5.4 to R5.6 (40 to 60% of the disk flowers blooming or already bloomed), or R5.7 to R5.9 (70 to 90% of the disk flowers blooming or already bloomed). Inoculations commenced August 12 (one day after fungicides were applied); no inoculations were conducted prior to applying fungicides. Approx. 30% (confection hybrid) and approx. 25% (oilseed hybrid) of sunflower heads had already passed R5.3 and approx. 15% (confection hybrid) and 10% (oilseed hybrid) had already passed R5.6 on August 12, and the inoculation treatments targeting R5.1-R5.3 or R5.4-R5.6 for inoculations also included these early-blooming plants that were at a more advanced stage of boom.

Spore solutions: Spore solutions were prepared by adding laboratory-grown ascospores of Sclerotinia sclerotiorum to non-chlorinated water and adding a one to two drops of Tween 20. Hand-held spray bottles were calibrated to determine how much liquid was released through each squirt of the bottle, and the spore solution was adjusted so that each squirt of the spray bottle delivered 10,000 spores. In each inoculation, 30,000 spores were delivered to the front of each head (3 squirts of the spray bottle).

Inoculations: At each inoculation, 30,000 spores were applied to the front of each head.

Irrigation: Overhead irrigation was applied through micro-sprinkler misting systems. From 9 pm on August 12 (when the first inoculations commenced) through 8 pm on Sept. 6, irrigation was applied 3 minutes every 15 minutes, 24 hours a day. From 8 pm on Sept. 6 through 5 pm on Sept. 18, irrigation was applied 3 minutes every 15 minutes for 8 to 12 hours a day and exclusively during daylight hours.

Disease assessment: On September 30 at the R8-R9 growth stage (confection hybrid; back of the head yellow to brown and bracts green to brown) and October 14 at the R9 growth stage (oilseed hybrid; maturity), every plant was assessed for the percent of the head exhibiting Sclerotinia head rot. All plants in each plot were evaluated.

Seed yield and quality assessment:

The oilseed hybrid was not harvested. Severe winds during the R6 growth stage caused severe lodging in many plots, and it was not possible to rigorously assess seed yield.

The confection sunflowers did not suffer wind damage and were harvested October 16.

Yields were calculated on the basis of a 5-ft plot width and the harvested plot length, and seed moisture was assessed after grain was cleaned. Seed yield was adjusted from the grain actual moisture to a standard 10% moisture level.

Sclerotia in the harvested grain: Percent sclerotia (by weight) was assessed by manually removing all sclerotia from a 200-gram subsample of harvested grain from each plot.

Sclerotia in the cleaned grain: Percent sclerotia (by weight) that could not be mechanically separated on the basis of size was assessed by manually separating all sclerotia from a 300-gram subsample of grain that had been cleaned by passing it through a shaker equipped with an upper sieve with 30/64 round holes and a lower sieve with 1/16 x 1/2 slotted holes.

Yield assessment: Yields were adjusted by the percent sclerotia in the cleaned grain such that reported yields represented excluded all sclerotia contamination.
Test weight assessment: Test weights were evaluated on a subsample of grain from which all sclerotia were manually removed.

Statistical analysis:

Data were evaluated with analysis of variance. Assumptions of ANOVA: (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 except the head rot incidence and severity index data within the non-inoculated treatments. To address these distributional problems, a systematic natural-log transformation [LN(x+1) for data sets that include values less than 1.0] was applied to these data. All other data met model assumptions. Within each inoculation treatment, analyses of fungicide application treatments were conducted with replicate and treatment as main factor effects. Combined analyses: Combined analyses of (1) fungicide applicaiton treatments across inoculation treatments and (2) inoculation treatments across fungicide application treatments treatments were conducted with replicate and irrigation treatment as main-factor effects and seeding rate & foliar fungicide treatment 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 (inoculation treatment) and the sub-factor (fungicide application 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. Software used for analyses: Analyses were implemented in PROC UNIVARIATE and PROC GLM of SAS (version 9.4; SAS Institute, Cary, NC).