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Keywords

Plant Pathology and Microbiology, Air-assist, Application, Disease, Fungicide, Nozzle Tip, Soybean, Canopy Penetration

Disciplines

Agricultural Science | Agriculture | Bioresource and Agricultural Engineering | Plant Pathology

Comments

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Nozzle and Carrier Application Effects on Control of Soybean Leaf Spot Diseases

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Abstract. *Increased soybean foliar disease potential has heightened grower interest in fungicide application techniques. Application field trials comparing application rate [187 vs. 112 L/ha (20 vs. 12 gal/acre)], nozzle style (twin-orifice; single-orifice) and spray quality (fine vs. medium and coarse spray quality), and application technique (with and without air-assist) along with an unsprayed check were done at two locations over two years. Fungicide deposition (coverage and droplet size) and disease severity in the bottom, middle, and top parts of the plant canopy, and soybean yield were measured. Fungicide deposition coverage reduced from the top (8%-18%) to the middle (4%-8%) to the bottom (1%-4%) of the canopy. Coverage was less affected by application treatment, however in wider rows [76-cm (30-in.)] coverage increased with the high-rate and air-assist treatments when spray quality was near the border between fine and medium. Conversely, in narrow rows [38-cm (15-in.)], least coverage was obtained with fine droplets produced by hollow-cone tips on an air-assisted sprayer. Size of droplets deposited generally followed predictions suggested by spray quality. Few disease severity differences were observed. Yield was unaffected by treatments sprayed during late reproductive stages (late R3 – R5) of the soybean plant.*

Keywords. *Air-assist, Application, Disease, Fungicide, Nozzle Tip, Soybean, Canopy Penetration.*

Soybeans (*Glycine max L.*) are a major commodity crop grown on over 30 million ha (75 million acres) in the United States (USDA, 2007). In Iowa, a large part of the cropland base, 4 million ha (10 million acres) annually, is devoted to soybean production. Although long-term crop yield trends are upward, soybean yield increases have been more stagnant than corn, the common companion rotational crop, causing growers to question factors such as disease that might be slowing yield growth.

In late 2004, the leaf spot disease Asian soybean rust (*Phakopsora pachyrhizi*) was detected in the United States. Since then it has been detected sporadically late in the season in the Midwest. Because of the potential for yield loss associated with this disease, as observed in other countries, grower concern has resulted in increased interest in managing this and other leaf spot diseases, namely brown spot (*Septoria glycines*), Cercospora leaf blight (*Cercospora kikuchii*), frogeye leaf spot (*C. sojina*) and downy mildew (*Peronospora manshurica*), that may be affecting yield. Midwestern U.S. agronomic row-crop growers are generally familiar and experienced with herbicide and insecticide application, but have very limited experiences in field application of fungicides. Growers customarily have existing sprayer equipment set up to apply systemic herbicides such as glyphosate (Owen and Hartzler, 2007) with relatively large droplets to reduce drift and carrier application rates of 94 to 143 L/ha (10 to 15 gal/acre) to minimize water transported and maximize the range of application area covered by an individual tank. Effective disease control is believed to be dependent on the amount of active ingredient deposited on and within the canopy and thus most recommended fungicide application methods include high spray pressure and hollow-cone nozzles to ensure fine droplet quality and adequate coverage. However, there are a few reports that suggest spray pressure and nozzle-type are not that important. All application technologies studied by Derksen et al. (2001) were equally effective at managing foliar disease in tomatoes. Similarly, Egel and Harmon (2001) found neither nozzle type nor spray pressure affected Alternaria leaf blight severity of muskmelon. Thus nozzle type could be chosen based on growers' preference, and the purchase of high pressure spray equipment was not necessary. Soybean rust and brown spot start in the lower canopy and progress up the plant, while frogeye leaf spot and downy mildew occur in mid-canopy. Thus, adequate coverage of the mid- and lower leaves of the canopy is important for leaf spot disease management.

Ozkan et al. (2006) found improved coverage and deposition with an air-assisted sprayer in the field within mature soybean canopy, although use of a canopy opener developed by Zhu et al. (2006) resulted in similar performance. Coverage and deposition from single-orifice, medium spray quality tips were generally greater than that from flat fan, twin-orifice, or hollow-cone tips producing coarse or fine spray quality (Ozkan et al., 2006). Wolf and Daggupati (2006) using a spray track compared various

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nozzle styles at 187 L/ha (20 gal/acre) and 16-km/h (10-mi/h) travel speed in laboratory and field trials. On average, single-orifice tips improved coverage slightly in the bottom canopy as compared to twin-orifice tips. Twin-orifice tips produced smaller droplets, but did not necessarily deposit more drops/cm^2 (droplet density) than single-orifice tips. On short-season, narrow-row [19 cm (7.5 in.)] soybean in North Dakota, Bradley et al. (2007) found spray coverage using single-orifice tips reduced in lower portions of the plant canopy and application of fungicide had no effect on yield. Coverage was not affected by spray treatment (including conventional and air-assisted sprayers), with the exception of a slight improvement in the lower canopy using a flat-fan tip on a conventional sprayer.

Characteristics of over-the-top, drop-nozzle, and air-assisted spray application in mature cotton were examined by Womac et al. (1992). Increased spray rate [from 47 to 94 L/ha (5 to 10 gal/acre)] predominantly increased deposition and chemical efficacy under most conditions. Howard et al. (1994) measured penetration and deposition of air-assisted sprayers as compared to a conventional over-the-top sprayer in cotton. Although results among sprayers were comparable in the top of the canopy, in the middle of the canopy air-assisted sprayers had increased deposition.

Objective

Because of the scarcity of information on foliar fungicide application techniques to Midwestern U.S. soybeans, field experiments were conducted to determine effects of nozzle type, carrier application, and application technique on droplet deposition on artificial targets within the crop canopy, foliar disease severity, and soybean yield. In particular, it was desired to compare the effects of: a) reduced carrier rate, b) larger droplet size common for herbicide application, and c) air-assisted sprayer with a spray application applying smaller droplet sizes at a greater than normal carrier application rate.

Methods And Materials

Treatments

To increase the chance of applying fungicides at a location with foliar disease pressure, experimental plots were conducted at two sites, Iowa State University's Agricultural Engineering and Agronomy Farm near Boone in central Iowa and Iowa State University's McNay Farm near Chariton in south-central Iowa.

The same 3-point-mounted sprayer was used (Falcon Vortex, Jacto Manufacturing, Pompeia, Brazil) for all application treatments except the first year at Chariton. The sprayer had a 14-m (46-ft) boom with control over four boom sections and capability of air-assist. When the fan operated (only in the air-assist treatments), a curtain of air exited a continuous slot directing nozzle output down into the plant canopy. The fan was adjusted for maximum speed. Air velocity measured 10 cm from the exit was 68 km/h (42 mi/h). During the first year at Chariton, an older custom-built research sprayer with a 4.6-m (15-ft) long boom was used. Both sprayers had nozzles placed on 51-cm (20-in.) centers.

Five treatments were used at each site in 2005 and six treatments were used in 2006 (table 1). In addition to an unsprayed check treatment, application treatments were common to both sites in both years with the exception that a single (but different) treatment was omitted from each site the first year. A relatively high 187 L/ha (20 gal/acre) application treatment was made with two-orifice nozzle tips listed by the manufacturer as producing droplets in the fine droplet spectrum (*ASABE Standards*, 2006). Nozzle size and operating pressure delivered a fine droplet spectrum at the desired application rate, however, a slight pressure decrease [34 kPa (5 psi)] would shift the droplet spectrum to medium quality according to the manufacturer (Spraying Systems, 2006). A lower application treatment, 112 L/ha (12 gal/acre), used two-orifice nozzle tips listed as also producing droplets in the fine droplet spectrum but at the lowest suggested operating pressure for that tip. A third treatment used single-orifice nozzle tips commonly used in soybeans for systemic herbicide application (Turbo TeeJet, Spraying Systems, Wheaton, Ill.). Although the carrier application rate was relatively high [168 L/ha (18 gal/acre)] the droplet spectrum produced as listed by the manufacturer was in the coarse droplet spectrum, but near the finer edge of the spectrum as a 69 kPa (10 psi) pressure increase would result in medium spray quality.

In 2005, a fourth application treatment at Boone was air-assisted with the air-curtain type sprayer applying at the high-rate application [187 L/ha (20 gal/acre)] with two-orifice nozzle tips. Due to resource limitations in transporting this sprayer, the fourth application treatment at

Table 1. Application treatments and operating conditions.

Treatment	Carrier Application Rate (L/ha)	Carrier Application Rate (gal/acre)	Nozzle[a]	Pressure (kPa)	Pressure (psi)	Speed (km/h)	Speed (mi/h)	Spray Quality[b]	Boone 2005	Boone 2006	Chariton 2005	Chariton 2006
High-rate	187	20	2-orifice 8004	276	40	9.6	6.0	Fine	X	X	X	X
Low-rate	112	12	2-orifice 8003	207	30	10.3	6.4	Fine	X	X	X	X
Herbicide-style	168	18	1-orifice, Turbo TeeJet 11003	276	40	8.0	5.0	Coarse	X	X	X	X
Air-assist	187	20	2-orifice 8004	276	40	9.6	6.0	Fine	X			
Air-assist	187	20	Hollow-cone, JA-3	648	94	6.4	4.0	Fine		X		X
Turbo Duo	187	20	2-orifice, Turbo TeeJet Duo 11002 (two tips)	276	40	9.6	6.0	Medium			X	
Turbo Twin jet	187	20	2-orifice Turbo 11004	276	40	9.6	6.0	Coarse		X		X
Unsprayed check									X	X	X	X

[a] Nozzles marketed by Spraying Systems Co. except JA-3 marketed by Jacto Co.
[b] Spray quality as listed in specifications supplied by manufacturer.

Chariton was instead an application with a Turbo TeeJet Duo nozzle (Spraying Systems, Wheaton, Ill.), new in the market that year. The nozzle consisted of two Turbo TeeJet tips mounted on a common nozzle body producing a medium droplet spectrum, according to the manufacturer, while applying a 187-L/ha (20-gal/acre) application.

For the second year, after consultation with the sprayer manufacturer, nozzle style on the air-assist treatment was changed to a hollow-cone tip (Jacto Manufacturing, Pompeia, Brazil) operating at higher pressure, but at the same application rate [187 L/ha (20 gal/acre)]. Also in the second year, the Turbo Duo treatment was replaced with a Turbo TwinJet tip, newly marketed for that product year by the manufacturer (Spraying Systems, Wheaton, Ill.). In this second year, both the air-assist and Turbo TwinJet treatments were used at both sites.

Site Details, Field Layout, and Measurements

Soybean row spacing at each site differed and reflected local planting practices. Row spacing at Boone was 76 cm (30 in.) in an east-west orientation and at Chariton was 38 cm (15 in.) in a north-south orientation. All treatments, including the unsprayed check were replicated in four field blocks at each location. Buffer areas at least one plot width wide were left unsprayed adjacent to each plot to avoid significant spray drift moving between plots. Boom height over the crop canopy was adjusted according to nozzle spray angle and spacing along the boom for manufacturer's specifications of each nozzle style in order to provide optimal overlap between nozzles across the full width of each plot.

At Boone individual plots were five rows wide (3.8 m, 12.5 ft) by 35 m (115 ft) long. A side section of the boom was used for fungicide application so that the tractor operating the sprayer did not travel through any plot areas. At Chariton during the first year, plots were 11 rows wide (4.2 m, 13.8 ft) by 61 m (200 ft) long with the sprayer tractor driving down the centerline of each plot. At Chariton during the second year, plots were 4.2 × 34 m (13.8 × 110 ft). A side section of the Falcon Vortex sprayer boom was used (as at Boone). Sprayer operation was always parallel to row direction except the second year at Chariton where sprayer operation was perpendicular (i.e. across) rows to accommodate field layout. Because a primary objective was to investigate deposition inside a full plant canopy, application was delayed until mid- to late reproductive growth stages of the soybean plant. Meteorology measurements (wind speed and direction, dry- and wet-bulb air temperature) were made several times during approximately 1.5 to 2.0 h of spray applications across all treatments at a location.

Tebuconazole fungicide (Folicur 3.6F, Bayer CropScience, Research Triangle Park, N.C.) was applied on all spray application treatments as suggested by the label at an active ingredient rate of 113 g/ha [1.55 oz a.i./acre or product rate of 0.292 L/ha (4 oz/acre)]. Tebuconazole belongs to the triazole class of fungicides and is a broad spectrum fungicide with systemic activity (Mueller and Bradley, 2008).

Measurements included droplet deposition on cards, foliar disease severity present on soybeans, and soybean yield. Measurement locations for deposition and foliar disease were at the bottom, middle, and top of the soybean plant canopy on eight soybean plants evenly spaced along a single measurement row within each plot. The measurement row location was selected to always be in the interior of the plot, but shifted off-center the first year at Chariton so as to be not directly adjacent to sprayer tractor wheel traffic or brushed by the tractor chassis.

Because of possible wet conditions from morning dew within the plant canopy, Kromekote paper (kkp) and dye were used rather than water-sensitive paper. Droplet collection cards [5 × 7.6 cm (2 × 3 in.)] constructed of Kromekote photographic paper were mounted with paper clips on individual leaf petioles in the measurement row on the low, mid-, and upper part of the canopy before spraying. Exact locations of the cards varied a bit depending on plant canopy height at the site, but were approximately 15, 38, and 61 cm (6, 15, and 24 in.) above the soil surface, respectively, and mounted on petioles oriented to an adjacent row. Weight of the card and paper clip caused petioles to droop slightly so that card orientation to the spray was perhaps 10 degrees closer to vertical than corresponding undisturbed upper leaf surfaces in the area. Orange spray paint was used to mark each plant on which cards were placed. Pink sprayer dye (Tracer Hot Pink Foam Dye, Precision Labs, Northbrook, Ill.) was mixed into the spray solution at a concentration of 0.275%. Although carrier application rates differed among treatments (table 1) the tank mix for each treatment was adjusted to apply the same rate per hectare (acre) of tebuconazole fungicide and concentration of sprayer dye in solution. Approximately one hour after spraying, cards were collected for later analysis. After droplet cards were scanned on a flatbed scanner, software (DropletScan; WRK of Arkansas, Lonoke, Ark.; and WRK of Oklahoma, Stillwater, Okla.; Devore Systems, Inc., Manhattan, Kans.) measured the number of droplets, droplet size, and area covered on each card.

Spray quality as categorized by the manufacturer according to ASABE (*ASABE Standards*, 2006) represents a range (e.g., fine, medium, course) of droplet sizes within the spray pattern produced by a nozzle in a mid-air, open area (i.e. without plant canopy) by laser measurement. Droplet sizes landing on deposition cards mounted within the plant canopy are affected by both the ability of droplets of various sizes to penetrate the canopy and also their ability to deposit on the card surface and spreading of the droplet at surface impact. General comparisons were made between the spray quality (droplet size range) predicted by the nozzle manufacturer and droplet size measured on deposition targets. These measures are different and thus not expected to strictly correlate, however applicators use manufacturer's spray quality as a tool in nozzle selection. Differences between spray quality predicted from the nozzle and droplet size measured on cards in the lower canopy may be due to filtering of droplets within upper regions of the plant canopy, droplets avoiding the target surface due to boundary air conditions, or assumptions regarding spread of the droplet on the card surface.

Spread factor and threshold values used by the software (Wolf, 2003) were based on laboratory measurements of water stains on white Kromekote paper rather than water stains on yellow water-sensitive paper. No additional surfactant was added and any difference in spread factor or threshold value using a mix with low-level concentrations of fungicide and dye were assumed to be minimal. Although exact values of droplet size may be uncertain, comparisons made across treatments using the same spread factor and threshold values should be valid unless factors are affected by individual spray treatment.

Near each of the droplet card measurement areas within the measurement row, a soybean trifoliate leaf sample was collected. Foliar disease severity (percent leaf area affected) was evaluated on each leaf sample to measure disease level. In the first year leaf samples for disease assessment were collected about two hours before spraying and again near the same measurement sites 19 to 20 days later. Because disease development is strongly influenced by environmental conditions after spraying rather than initial incidence of disease, in the second year leaf samples only were collected once (21 days after fungicide application at Boone, and 26 days after fungicide application at McNay) and evaluated for four specific diseases. Harvested soybean yield was measured at the end of each season by harvesting interior plot rows.

Statistical Analysis

Deposition, foliar disease, and yield data were statistically analyzed in analyses of variance to determine if observed treatment means were statistically different. Because measurements were made in the field, treatment differences were noted when measurements were significant at a 90% confidence level.

Results and Discussion

Field conditions at the time of spraying are listed in table 2.

Deposition

Deposition measurements from droplet cards near the bottom of the soybean leaf canopy are shown in table 3. Spray droplet volume diameters are listed for the droplet size below which 10% ($D_{V0.1}$), 50% ($D_{V0.5}$), and 90% ($D_{V0.9}$) of the spray volume was being applied.

In 2005 at the Boone location, the coarser spray quality of nozzles in the herbicide-style treatment resulted in larger $D_{V0.5}$ and $D_{V0.9}$ values as expected. At Chariton, results were similar at $D_{V0.5}$ and $D_{V0.9}$ however deposition droplet size at $D_{V0.1}$ was largest for the Turbo Duo treatment. High-rate application had the greatest droplet density.

In 2006 droplets from hollow-cone tips of the air-assist treatment were smaller than other treatments. At the Boone site, droplet size at $D_{V0.5}$ and $D_{V0.9}$ levels followed: herbicide-style > Turbo TwinJet = high-rate > low-rate treatment. At Chariton, droplets deposited by the herbicide-style and Turbo TwinJet treatment were larger than those of the low-rate treatment.

Deposition measurements in the middle of the leaf canopy are shown in table 4. In 2005 at Boone, deposited droplet size at $D_{V0.5}$ and $D_{V0.9}$ levels followed herbicide-style>high-rate =air-assist>low-rate. $D_{V0.5}$ and $D_{V0.9}$ droplet size levels at Chariton followed herbicide-style>Turbo Duo=high-rate> low-rate.

In 2006 at Boone, herbicide-style, Turbo TwinJet, and high-rate treatments deposited larger droplets than did the low-rate and air-assist treatments. Similarly at Chariton the herbicide-style and Turbo TwinJet treatments deposited larger droplets than the low-rate treatment. Droplets deposited from the hollow-cone tips of the air-assist treatment were even smaller than those of the low-rate treatment. At Boone the air-assist treatment applied greater droplet density in the middle canopy. At Chariton, percent area covered for the air-assist treatment was lower than other treatments.

Deposition values at the top of the leaf canopy are shown in table 5. In 2005 at the Boone site, both $D_{V0.5}$ and $D_{V0.9}$ values were greatest for the herbicide-style treatment, intermediate for the high-rate and air-assist treatments, least for the low-rate treatment. $D_{V0.1}$ values were greatest for the herbicide-style and air-assist treatments, intermediate for the high-rate treatment and least for the low-rate treatment. At the Chariton site, $D_{V0.5}$ and $D_{V0.9}$ for the herbicide-style treatment was greater than for the low- and high-rate treatments.

In 2006 at Boone, larger droplets were deposited by herbicide-style, Turbo TwinJet, and high-rate applications (similar to mid- and bottom-canopy measurements). At Chariton, droplets deposited by herbicide-style and Turbo TwinJet treatments were largest and those deposited by the air-assist treatment were smallest.

In the top of the canopy during 2005 at Boone, the air-assist and high-rate treatments had greater droplet density and area covered. In 2006 in the narrower rows at Chariton, the air-assist treatment had reduced coverage than most others. Although the low-rate treatment was set to apply less total volume per unit of land area, it had greater droplet density than other treatments.

Droplet sizes deposited on target cards as measured by D_V values generally corresponded to spray quality predicted by manufacturers. An exception in 2006 occurred when droplets deposited by the high-rate treatment (fine) were similar to herbicide-style and Turbo TwinJet treatments (coarse) at both locations. Percentage area covered and droplet density were often similar among treatments, particularly in lower regions of the canopy. Exceptions at the top of the plant canopy included at Boone (2005) air-assist and high-rate applications had greater coverage and droplet density and at Chariton (2006) greatest droplet density was at the low-rate application. In the middle of the plant canopy the second year, the air-assist application had the greatest droplet density at Boone, but the least coverage area at Chariton. In

Table 2. Field conditions during application[a].

Location	Date	Air Temp. (°C)	Air Temp. (°F)	Relative Humidity (%)	Wind Direction	Wind Speed (km/h)	Wind Speed (mi/h)	Soybean Growth Stage
Boone	27 Jul-05	24	75	38	NNW	4.8 - 9.6	3 - 6	Early R4
Chariton	29 Jul-05	29	85	44	SSW	3.2 - 8.0	2 - 5	Late R3
Boone	11 Aug-06	26	78	53	ESE	6.4 - 8.0	4 - 5	R5
Chariton	15 Aug-06	27	81	23	S	1.6 - 4.8	1 - 3	R5

[a] Seeding rate was 370,000 seeds/ha (150,000 seeds/acre) except Boone, 2005 [435,000 seed/ha (176,000 seeds/acre)].

Table 3. Droplet measurements from collection cards near bottom of soybean leaf canopy.

Site/Treatment	Area (%)	Area (drops/cm^2)	Volume Diameter (µm) 0.1[a]	0.5[b]	0.9[c]
Boone, 2005					
High-rate	1.73	28.5	128	225	379
Low-rate	0.75	13.8	120	255	379
Herbicide-style	1.28	15.3	143	354	558
Air-assist	1.10	18.3	130	268	424
$LSD_{\alpha=0.10}$[d]	NS[e]	NS	NS	64	41
Chariton, 2005					
High-rate	6.40	85.0	137	307	497
Low-rate	1.78	31.0	125	265	414
Herbicide-style	3.95	41.8	152	390	610
Turbo Duo	3.53	25.0	166	350	527
$LSD_{\alpha=0.10}$	NS	38.1	25	45	38
Boone, 2006					
High-rate	0.80	7.8	181	333	493
Low-rate	1.28	19.0	159	262	394
Herbicide-style	1.65	15.0	223	401	563
Air-assist	1.10	32.3	115	183	285
Turbo TwinJet	1.85	19.3	189	326	494
$LSD_{\alpha=0.10}$	NS	NS	60	47	59
Chariton, 2006					
High-rate	1.03	13.5	182	298	565
Low-rate	1.65	24.3	151	262	440
Herbicide-style	1.93	19.8	182	326	617
Air-assist	0.70	19.8	95	159	235
Turbo TwinJet	2.30	22.3	191	334	511
$LSD_{\alpha=0.10}$	NS	NS	28	39	146

[a] $D_{V0.1}$; 10% of spray volume is contained in droplets smaller than this size.
[b] Volume median diameter; 50% of spray volume is contained in droplets smaller than this size.
[c] $D_{V0.9}$; 90% of spray volume is contained in droplets smaller than this size.
[d] Least significant difference at 90% confidence level for a card position at a specific location.
[e] No significant difference.

Table 4. Droplet measurements from collection cards near middle of soybean leaf canopy.

Site/Treatment	Area (%)	Area (drops/cm^2)	Volume Diameter (µm) 0.1[a]	0.5[b]	0.9[c]
Boone, 2005					
High-rate	6.48	68.5	145	317	483
Low-rate	3.73	54.0	132	250	401
Herbicide-style	4.85	40.5	153	378	604
Air-assist	7.75	72.5	168	321	483
$LSD_{\alpha=0.10}$[d]	NS[e]	NS	22	57	71
Chariton, 2005					
High-rate	8.13	91.5	150	335	531
Low-rate	4.25	56.0	143	302	464
Herbicide-style	10.65	69.3	198	461	708
Turbo Duo	7.75	56.0	180	375	551
$LSD_{\alpha=0.10}$	NS	NS	24	46	66
Boone, 2006					
High-rate	3.38	27.0	198	355	533
Low-rate	3.85	47.8	153	277	437
Herbicide-style	7.88	46.0	199	399	613
Air-assist	5.93	116.0	132	230	348
Turbo TwinJet	10.55	62.8	205	392	585
$LSD_{\alpha=0.10}$	NS	36.6	25	60	69
Chariton, 2006					
High-rate	3.88	38.8	180	315	486
Low-rate	4.68	57.3	160	269	436
Herbicide-style	5.58	30.0	202	396	612
Air-assist	1.30	29.3	124	208	355
Turbo TwinJet	5.60	50.5	194	348	527
$LSD_{\alpha=0.10}$	2.54	NS	13	24	73

[a] $D_{V0.1}$; 10% of spray volume is contained in droplets smaller than this size.
[b] Volume median diameter; 50% of spray volume is contained in droplets smaller than this size.
[c] $D_{V0.9}$; 90% of spray volume is contained in droplets smaller than this size.
[d] Least significant difference at 90% confidence level for a card position at a specific location.
[e] No significant difference.

the bottom of the canopy, the high-rate treatment had the greatest droplet density at Boone the first year.

Because much applicator interest centers on the ability to deposit spray material in lower parts of the plant canopy, results have been shown in tables 3, 4, and 5 by canopy location. To test whether deposition is reduced at lower canopy locations and further investigate subtle overall differences between treatments with a larger data set, all data were pooled (i.e., all three canopy locations) for separate analyses within each site and year. In 2005, percentage area covered and droplet density were statistically greatest at the top of the canopy, intermediate in the middle, and least at the bottom (table 6). Mean top coverage was 18% at Boone and 17% at Chariton, but ranged from 1% to 8% mean coverage at the bottom or middle canopy positions depending on site and canopy position. Bradley et al. (2007) also reported similar results in their work on soybeans, that is, coverage in the upper canopy was considerably greater than coverage in the lower canopy. Deposited droplet size was reduced at lower canopy locations. At the Boone site the air-assist and high-rate treatments had greater percentage coverage and droplet density than other treatments. At Chariton the high-rate treatment had greater droplet density than other treatments.

Again in 2006, percentage area covered, droplet density, and deposited droplet size were reduced as canopy position moved to lower areas (table 7). At Boone, the air-assist treatment deposited statistically more droplet density than other treatments, but the Turbo TwinJet treatment had statistically greater percentage coverage than most other treatments. Droplet density was greatest for the low-rate treatment and percent coverage was least for the air-assist treatment at Chariton.

Discussion of Application and Nozzle Effect on Deposition

Evaluating results from specific locations within the plant canopy (bottom, middle, and top) as well as results from the pooled data suggested that the air-assist treatment increased coverage in 76-cm (30-in.) rows in the top and middle parts

Table 5. Droplet measurements from collection cards near top of soybean leaf canopy.

Site/Treatment	Area (%)	Area (drop/cm^2)	Volume Diameter (µm) 0.1[a]	0.5[b]	0.9[c]
Boone, 2005					
High-rate	21.18	156.3	181	395	637
Low-rate	9.53	115.5	147	302	460
Herbicide-style	16.68	86.5	200	470	710
Air-assist	24.23	148.8	202	394	594
$LSD_{\alpha=0.10}$[d]	3.66	26.5	13	26	53
Chariton, 2005					
High-rate	18.23	155.0	205	445	725
Low-rate	14.65	100.3	192	400	634
Herbicide-style	20.25	90.0	228	530	806
Turbo Duo	12.90	62.3	234	472	691
$LSD_{\alpha=0.10}$	NS[e]	NS	NS	68	67
Boone, 2006					
High-rate	16.28	95.0	224	442	645
Low-rate	9.33	95.8	175	339	503
Herbicide-style	18.30	83.8	238	499	707
Air-assist	10.07	108.3	169	310	486
Turbo TwinJet	18.43	82.3	239	478	693
$LSD_{\alpha=0.10}$	NS	NS	26	55	82
Chariton, 2006					
High-rate	7.93	61.0	191	367	549
Low-rate	12.50	108.8	178	348	533
Herbicide-style	7.60	40.5	226	441	648
Air-assist	2.05	39.0	141	253	418
Turbo TwinJet	8.45	61.8	227	425	613
$LSD_{\alpha=0.10}$	5.78	38.7	30	50	82

[a] $D_{V0.1}$; 10% of spray volume is contained in droplets smaller than this size.
[b] Volume median diameter; 50% of spray volume is contained in droplets smaller than this size.
[c] $D_{V0.9}$; 90% of spray volume is contained in droplets smaller than this size.
[d] Least significant difference at 90% confidence level for a card position at a specific location.
[e] No significant difference.

Table 6. Droplet measurements from collection cards in all locations within leaf canopy, 2005.

Position/Treatment	Area (%)	Area (drop/cm^2)	Volume Diameter (µm) 0.1[a]	0.5[b]	0.9[c]
Boone					
Canopy position					
Top	17.90	126.8	182	390	600
Middle	5.70	58.9	149	316	492
Bottom	1.21	18.9	130	275	435
$LSD_{\alpha=0.10}$[d]	1.52	12.1	11	23	26
Treatment					
High-rate	9.79	84.4	151	312	500
Low-rate	4.67	61.1	133	269	413
Herbicide-style	7.60	47.4	165	400	624
Air-assist	11.03	79.8	167	328	500
$LSD_{\alpha=0.10}$[e]	1.76	13.9	12	27	30
Chariton					
Canopy position					
Top	16.51	101.9	215	462	714
Middle	7.69	68.2	167	368	564
Bottom	3.91	45.7	145	328	512
$LSD_{\alpha=0.10}$[d]	3.34	23.7	16	27	38
Treatment					
High-rate	10.92	110.5	164	362	584
Low-rate	6.89	62.4	153	322	504
Herbicide-style	11.62	67.0	193	460	708
Turbo Duo	8.06	47.8	193	399	590
$LSD_{\alpha=0.10}$[e]	NS[f]	27.4	18	31	44

[a] $D_{V0.1}$; 10% of spray volume is contained in droplets smaller than this size.
[b] Volume median diameter; 50% of spray volume is contained in droplets smaller than this size.
[c] $D_{V0.9}$; 90% of spray volume is contained in droplets smaller than this size.
[d] Least significant difference at 90% confidence level for a specific canopy position across all treatments.
[e] Least significant difference at 90% confidence level for a specific treatment across all canopy positions.
[f] No significant difference.

of the plant canopy (Boone, 2005). Alternatively the air-assist treatment with hollow-cone nozzles had reduced deposition, particularly in lower parts of the plant canopy and within narrow 38-cm (15-in.) rows (Chariton, 2006). At Chariton in 2006 with conditions of a full plant canopy (soybean growth stage R5) and application perpendicular to rows coverage generally increased with the Turbo TwinJet and (unexpectedly) the low-rate applications. At Boone in 2006, although hollow-cone tips of the air-assist treatment produced greater droplet density, percentage of area covered was numerically less than most other treatments. Whether greater droplet density or percentage of area covered are preferred may be impacted by the degree to which the fungicide is locally systemic within areas of a leaf.

Results suggested that in a full soybean plant canopy, narrow rows, and/or spraying perpendicular to rows, droplet size should not be severely reduced to penetrate the mid- and lower canopy. Avoiding the use of extremely fine droplets agreed with results reported by Ozkan et al. (2006) and Wolf and Daggupati (2006). The relative size of droplets deposited on cards left by various application treatments within the soybean canopy generally followed manufacturer's predicted spray quality, except the second year when droplets deposited by the high-rate treatment were about the size of those deposited by Turbo TwinJet and herbicide-style treatments. Travel speeds differed among application treatments (table 1) to accommodate desired application rates and were in the mid- or lower range of those typical for tractor operated field sprayers. Any speed differences between treatments were assumed to have minimal affect on deposition. Differences in coverage and droplet density were greater at different heights within the plant canopy (i.e. values reduced as location within canopy was lower) than among application treatments (tables 6 and 7).

Efficacy of Application Treatments and Yield

Leaf disease severity in 2005 immediately before fungicide applications and almost three weeks after application are shown in table 8. Dry environmental conditions during August were not conducive for the

Table 7. Droplet measurements from collection cards in all locations within leaf canopy, 2006.

Position/Treatment	Area (%)	Area (drop/cm^2)	Volume Diameter (μm) 0.1[a]	0.5[b]	0.9[c]
Boone					
Canopy position					
Top	14.71	92.2	211	419	613
Middle	6.34	56.9	180	336	511
Bottom	1.35	17.9	176	307	454
$LSD_{\alpha=0.10}$[d]	2.26	12.2	16	22	29
Treatment					
High-rate	6.82	43.3	201	376	557
Low-rate	4.82	54.2	162	292	445
Herbicide-style	9.28	48.3	220	433	627
Air-assist	5.70	85.6	139	241	373
Turbo TwinJet	10.28	54.8	211	398	590
$LSD_{\alpha=0.10}$[e]	2.93	15.7	21	29	37
Chariton					
Canopy position					
Top	7.71	62.2	192	367	552
Middle	4.21	41.2	172	307	483
Bottom	1.52	19.9	160	276	473
$LSD_{\alpha=0.10}$[d]	1.70	12.8	12	20	42
Treatment					
High-rate	4.28	37.8	184	327	533
Low-rate	6.28	63.4	163	293	469
Herbicide-style	5.03	30.1	203	388	626
Air-assist	1.35	29.3	120	206	336
Turbo TwinJet	5.45	44.8	204	369	551
$LSD_{\alpha=0.10}$[e]	2.19	16.6	15	26	55

[a] $D_{V0.1}$; 10% of spray volume is contained in droplets smaller than this size.
[b] Volume median diameter; 50% of spray volume is contained in droplets smaller than this size.
[c] $D_{V0.9}$; 90% of spray volume is contained in droplets smaller than this size.
[d] Least significant difference at 90% confidence level for a specific canopy position across all treatments.
[e] Least significant difference at 90% confidence level for a specific treatment across all canopy positions.

development of soybean foliar diseases. Only brown spot and frogeye leaf spot were present at both sites, but at very low disease severity. Fungicide applications generally decreased the amount of disease observed, however low disease pressure precluded detecting any differences among application treatments or with the unsprayed check.

More frequent August precipitation events in 2006 (than 2005) resulted in greater foliar soybean disease pressure. Asian soybean rust again did not occur at either site, however, brown spot, Cercospora leaf blight, downy mildew and frogeye leaf spot were observed at both sites. Differences among application treatments are shown in tables 9 and 10. The unsprayed check had greater incidence of Cercospora leaf blight in mid-canopy than did sprayed treatments at the Boone location. Also percentage frogeye leaf spot was greater at the bottom of the canopy in the unsprayed check than in the low-rate, air-assist, or Turbo TwinJet applications at Chariton. The general lack of significance of application method agreed with both Egel and Harmon's (2001) and Derksen et al.'s (2001) results finding fungicide application method had little affect on foliar disease severity in muskmelon and tomato, respectively.

Table 8. Soybean leaf disease severity in bottom, middle, and top of leaf canopy before and after spraying, 2005[a].

Site/Treatment	Before Spraying Bottom	Middle	Top	After Spraying Bottom	Middle	Top
Boone						
High-rate	0.97	0.05	0.00	0.58	0.00	0.00
Low-rate	1.28	0.16	0.02	0.64	0.00	0.00
Herbicide-style	0.75	0.00	0.00	0.61	0.23	0.00
Air-assist	0.77	0.09	0.00	0.81	0.03	0.00
No spray	1.05	0.06	0.02	0.75	0.41	0.00
$LSD_{\alpha=0.10}$[b]	NS[c]	NS	NS	NS	NS	NS
Chariton						
High-rate	0.78	0.20	0.02	0.92	0.19	0.00
Low-rate	0.97	0.17	0.03	0.64	0.13	0.00
Herbicide-style	1.03	0.16	0.00	0.58	0.09	0.05
Turbo Duo	0.50	0.27	0.00	0.84	0.14	0.00
No spray	0.66	0.33	0.00	0.69	0.09	0.00
$LSD_{\alpha=0.10}$	NS	NS	NS	NS	NS	NS

[a] Severity scale:
0 = no disease
0.5 = few spots
1 = <15% of leaf area with disease
2 = 15%-24% leaf area with disease
[b] Least significant difference at 90% confidence level for a leaf position at a specific location.
[c] Differences are not statistically significant.

Perhaps because disease pressure among treatments was limited, harvested soybean yields and moisture content at harvest (as a gauge of maturity) were also statistically

Table 9. Brown spot and frogeye leaf disease severity[a] in bottom, middle, and top of soybean leaf canopy, 2006.

Site/Treatment	Brown Spot Bottom	Middle	Top	Frogeye Bottom	Middle	Top
Boone						
High-rate	10.32	0.44	0.00	0.59	1.35	1.10
Low-rate	19.35	0.00	0.00	0.41	1.25	1.38
Herbicide-style	12.26	2.81	0.00	0.12	1.00	0.97
Air-assist	9.90	0.00	0.00	0.30	1.44	1.41
Turbo TwinJet	11.65	0.00	0.00	0.44	0.97	0.60
No spray	18.04	0.00	0.00	0.66	0.91	0.97
$LSD_{\alpha=0.10}$[b]	NS[c]	NS	NS	NS	NS	NS
Chariton						
High-rate	13.25	0.00	0.00	0.79	1.04	2.04
Low-rate	3.13	0.00	0.00	0.28	2.30	0.83
Herbicide-style	3.32	0.13	0.00	0.75	1.07	1.01
Air-assist	5.38	2.32	0.00	0.25	1.00	1.25
Turbo TwinJet	1.21	0.00	0.00	0.29	0.92	0.33
No spray	8.41	1.85	0.00	1.35	2.10	1.51
$LSD_{\alpha=0.10}$	NS	NS	NS	0.70	NS	NS

[a] Disease severity = mean percentage leaf area with disease (N = 32 at each location and treatment).
[b] Least significant difference at 90% confidence level for a leaf position at a specific location.
[c] Differences are not statistically significant.

Table 10. Downy mildew severity[a] and incidence[b] of Cercospora leaf blight in bottom, middle, and top of soybean leaf canopy, 2006.

Site/Treatment	Downy Mildew Bottom	Downy Mildew Middle	Downy Mildew Top	Cercospora Leaf Blight Bottom	Cercospora Leaf Blight Middle	Cercospora Leaf Blight Top
Boone						
High-rate	0.00	0.06	0.28	0.00	0.03	0.32
Low-rate	0.00	0.13	0.13	0.00	0.00	0.25
Herbicide-style	0.00	0.03	0.13	0.00	0.00	0.25
Air-assist	0.00	0.19	0.25	0.00	0.00	0.06
Turbo TwinJet	0.00	0.38	0.44	0.00	0.00	0.28
No spray	0.00	0.13	0.47	0.00	0.22	0.32
$LSD_{\alpha=0.10}$[c]	NS[d]	NS	NS	NS	0.15	NS
Chariton						
High-rate	0.00	1.50	0.71	0.00	0.21	0.34
Low-rate	0.13	0.21	0.71	0.00	0.00	0.17
Herbicide-style	0.00	0.13	0.57	0.00	0.07	0.13
Air-assist	0.00	0.44	1.00	0.00	0.00	0.07
Turbo TwinJet	0.00	0.54	2.08	0.00	0.00	0.29
No spray	0.00	0.28	0.32	0.03	0.10	0.22
$LSD_{\alpha=0.10}$	NS	NS	NS	NS	NS	NS

[a] Disease severity = mean percentage leaf area with disease (N = 32 at each location and treatment).
[b] Incidence equals fraction (0 to 1.00) of leaves with cercospora leaf blight.
[c] Least significant difference at 90% confidence level for a leaf position at a specific location.
[d] Differences are not statistically significant.

Table 11. Soybean yields (adjusted to 13%) and moisture content at harvest for fungicide application treatments.

Location/Treatment	Yield (Mg/ha) 2005	Yield (Mg/ha) 2006	Yield (Bu/acre) 2005	Yield (Bu/acre) 2006	Moisture Content (%) 2005	Moisture Content (%) 2006
Boone						
High-rate	4.36	3.27	64.9	48.6	13.1	13.0
Low-rate	4.12	3.13	61.2	46.5	12.9	14.6
Herbicide-style	4.20	3.21	62.4	47.7	12.9	14.9
Air-assist	4.22	3.13	62.8	46.5	12.9	14.1
Turbo TwinJet		3.36		49.9		13.7
No spray	4.21	3.16	62.7	47.0	12.9	13.9
$LSD_{\alpha=0.10}$[a]	NS[b]	NS	NS	NS	NS	NS
Chariton						
High-rate	3.31	3.56	49.2	53.0	15.0	13.6
Low-rate	3.03	3.61	45.0	53.7	14.8	13.7
Herbicide-style	3.26	3.47	48.5	51.6	15.4	13.6
Air-assist		3.64		54.1		13.8
Turbo Duo	3.11		46.3		15.2	
Turbo TwinJet		3.58		53.3		13.6
No spray	2.93	3.58	43.5	53.3	14.8	13.7
$LSD_{\alpha=0.10}$	NS	NS	NS	NS	NS	NS

[a] Least significant difference at 90% confidence level for a treatment at a specific location.
[b] Differences are not statistically significant.

equivalent across all application treatments and the unsprayed check (table 11). Tebuconazole did not affect soybean yield in similar field trials in North Dakota (Bradley et al., 2007). Although crop yield in this study was unaffected by fungicide application treatment, results may have been different under high disease pressure.

Summary and Conclusions

Within the range of conditions encountered at two field sites during two years, data support the following conclusions:

Deposition:

- Relative size of droplets deposited on cards within the canopy by application treatments generally followed manufacturer predicted spray quality from coarse to medium to fine droplets for the treatments. An exception was in year two when droplets of the high-rate [187 L/ha (20 gal/acre)] treatment (fine) were closer to those of the herbicide-style and Turbo TwinJet treatments (coarse).
- Percentage area covered and droplet density were often similar among treatments within separate canopy locations, particularly at bottom- and middle-canopy locations. Pooling data from the top-, middle-, and bottom-canopy locations, the air-assist and high-rate treatments had greater percentage area coverage and droplet density at Boone [76-cm (30-in.) row spacing] the first year. In the second year at Boone although the air-assist treatment had greater droplet density, the Turbo TwinJet and herbicide-style treatments had greater percentage coverage. In narrower [38-cm (15-in.)] rows at Chariton the second year, percentage coverage of the air-assist treatment was lower than all other treatments. Droplet density was greatest at Chariton for the high-rate treatment the first year, but the low-rate treatment the second year. Except for the second year at Chariton, production of smaller droplets often increased droplet density.
- When all data was pooled (all canopy locations) within each site and year, percentage area covered and droplet density were always statistically greater at the top of the canopy (8%-18% coverage) than at the middle (4%-8% coverage) and middle values were greater than at the bottom (1%-4% coverage). The size of droplets deposited (D_v values) was reduced at lower positions within the canopy.

Foliar disease and yield:

- No conclusions can be drawn on the effect of application methods on leaf disease management because of the low disease pressure that existed in both years.
- Soybean yield was not affected by application treatments or as compared to the unsprayed check. In order to observe application within dense plant canopy, application was delayed until later reproductive stages in August (i.e. yield effect was not tested by earlier application). Bradley et al. (2007) also reported that applications of tebuconazole at growth stage R5 did not result in a positive yield response on soybeans.

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