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Aerial Application Methods for Increasing Fungicide Deposition on Corn

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Abstract: Corn, Zea mays L. is the most widely produced feed grain in the United States and accounted for nearly 95% of total feed grain production in 2017. Using conventional hydraulic and electrostatically charged nozzles and rotary atomizers, pyraclostrobin fungicide was aerially applied at 10 and 19 L/ha on VT stage corn. Fluorescent dye deposits on an artificial sampler and corn foliage were measured and quantitated using fluorometric analysis. Image analysis described spray droplets captured on water sensitive papers (WSP). The AU5000 rotary atomizers at 19 L/ha produced significantly greater deposits on artificial collectors compared to other application methods in both top and mid canopy regions. Similarly, deposition on corn leaves was significantly greater for the AU5000 rotary atomizer than that for the other delivery systems, except in the mid canopy where deposition was comparable to the hydraulic nozzle. Droplet density, % coverage and the spray rate were also significantly higher for the AU5000 rotary atomizer on WSPs. The aerial application of fungicides with AU5000 rotary atomizers at 19 L/ha and a volume median diameter ~ 255 µm significantly improved fungicide deposition on corn. These results provide guidance to aerial applicators for increased fungicide applications on corn foliage.

Keywords: Aerial Sprays, Fungicide, Zea Mays, Corn, Spray Deposition, Spray Nozzles, Electrostatic Charging

1. Introduction

Corn, *Zea mays* L. is the most widely produced feed grain in the United States with more than 90 million acres planted predominantly in the Heartland region during 2015, and accounted for nearly 95% of total feed grain production in the country in 2017 [1]. It also represents the largest component of the livestock feed industry in the United States with nearly 20% of its produce exported to various countries adding nearly $75 billion to the US economy [2]. The Energy Independence and Security Act of 2007 mandated an increase in biofuel use from 9 billion gallons in 2008 to 36 billion gallons in 2022, of which 15 billion gallons can be produced from corn [3]. With increasing demand for corn as feed, biofuel and export, corn acreage is replacing soybeans and wheat, transforming the agricultural landscape in the United States [4]. With 5 billion bushels of corn used for ethanol production annually and it is expected to make up almost 35% of total use in 10 years and that with the elimination of MTBE (methyl tertiary butyl ether) as a fuel additive concomitant with increasing global demand for crude oil, there is a greater impetus for large expansion of maize production in the United States [5, 6].

Foliar diseases such as common rust, *Puccinia sorghi* Schweinitz, southern rust, *P. polyspora* Underwood and grey leaf spot, *Cercospora zeae-maydis* Tehon & E. Y. Daniels were the most common diseases of corn for which fungicides were used in the United States [7, 8]. Also, fungicides to control Northern leaf blight, *Setosphaeria turcica* (L.) Leonard & Suggs and Northern leaf spot, caused by *Bipolaris zeicola* (G. L. Stout) Shoemaker have also been reported [9-11]. Researchers have reported that yield loss in corn due to fungal foliar diseases was considerable [11-15]. An economic analysis of fungicide use to control foliar diseases of corn for seed production indicated that 79% of fungicide treatments were profitable to the growers in the United States [16]. However, Paul *et al.* [17] reported that the use of foliar fungicides was unlikely to be profitable when the disease severity was low and yield expectation was high. Nevertheless, the application of fungicides for the suppression of foliar diseases is important for increasing plant health, diminish disease risk and to improve yield [18]. In fact, strobilurin fungicides have been shown to be physiologically beneficial by increasing photosynthesis and plant health [19-21].

The development of application technology to control foliar diseases is critical to maintain and sustain increased corn grain yield in the United States. Several researchers have reported on improved application techniques to increase deposition and penetration of fungicides to various crops. Fritz *et al*. [22] reported on aerial application techniques using hydraulic nozzles at two spray rates and two droplet sizes along with rotary atomizers and electrostatic nozzles for increasing fungicide deposition on wheat spikelets. Geary *et al*. [23] compared aerially applied fungicides on potato before and after the closure of the crop canopy and found that multiple applications of the chemical were needed for adequate protection against late blight infection. Washington [24] reported that the aerial application of fungicides with droplet density ~ 30/cm^2 and volume median diameter between 300 to 400 µm will increase deposition and disease control on banana. Washington *et al*. [24] found that detectable fungicide deposition was observed only when on banana leaf target was vertically oriented. Wolfe *et al*. [25] conducted low volume aerial applications of pyraclostrobin fungicide with adjuvants on corn and compared droplet spectra, coverage, yield and disease control and found mixed results between application methods. Bayer *et al*. [26] evaluated aerial applications of fungicide on irrigated rice with rotary atomizers, hydraulic and electrostatic nozzles and found that the penetration of spray droplets was higher for the rotary atomizers at 15 L/ha than for either the hydraulic or electrostatic nozzles.

This study was conducted to assess and characterize the deposition of a fungicide on corn using selected aerial delivery systems with low volume spray applications. The intent was to define fungicide deposition to VT stage corn from electrostatic, conventional CP nozzles and rotary atomizers in concert with low volume spray rates and on the use of this data to optimize aerial application methods for improved fungicide deposition.

2. Materials and Methods

2.1. Study Site and Application of Materials

This study was conducted near College Station, Texas (30.60°N, 96.31°W) in a commercial corn field with a center pivot irrigation system. The study plots comprising of 7 to 12 ha were assembled in a completely randomized design with three replications (Figure 1). The water-based spray solution comprised of a pyraclostrobin fungicide (Headline®, BASF Corp., Research Triangle Park, NC) mixed at 0.438 L/ha, a high surfactant oil concentrate, Superb® HC (Winfield Solutions, St. Paul, MN) mixed at 0.624 ml/L and a Caracid Brilliant Flavine FFS fluorescent dye (Carolina Color and Chemical Co., Charlotte, NC) mixed at 37 gm/ha. All treatments were applied by a turbine powered Air Tractor, AT-402B (Air Tractor, Inc., Olney, TX). The treatments comprised of electrostatically charged nozzles (Figure 2A), CP-11TT conventional hydraulic nozzles (Figure 2B), AU-5000 (Figure 2C) and ASC rotary atomizers (Figure 2D) and an untreated check. The untreated check plots (T8) were sprayed with water and the nonionic surfactant. Table 1 describes treatments, nozzle specifications and aircraft's operational parameters. The abbreviation used for each treatment in table 1 and thereafter in figures describes the nozzles and the spray rates. For instance, CP-1 and CP-2 denote hydraulic nozzle at 2 spray rates (10 and 19 L/ha). Similarly, all other treatment nozzles were described by appropriate abbreviations. CP11-TT flat fan nozzle with a deflection angle of 90° decreased the droplet spectra of the spray solutions. Rotary atomizers have a rotating cage through which a spray plume is released and atomized at 2,000 to 10,000 revolutions per minute. They produce a narrower controlled spectrum of spray droplets with smaller droplet size and higher droplet density comparable to electrostatically charged nozzles [27-30]. Electrostatic nozzles induce a charge on spray droplets by an applied electric field between the grounded nozzle and the electrode encircling the spray cone. Larger electric fields increase the induced charge on the droplets. More charge can be placed on the droplets by increasing the applied electric field. However, too large an electric field can cause the system to short-out. The pilot optimizes the charge on the spray by setting the applied current equal on both left and right booms while staying below the "short-out" voltage. Each study plot received three swaths of spray at a boom height of 3-m above canopy and with a swath width of 20 m. Plots were located within the irrigated portion of the field and the sample areas were at least 100-m inside the field to minimize any field edge effects. During each test, the prevailing wind was approximately 90° across the corn rows and parallel to the line of flight. The meteorological data describing the weather conditions during the study were given in table 2 and showed that weather conditions remained relatively constant between treatments.

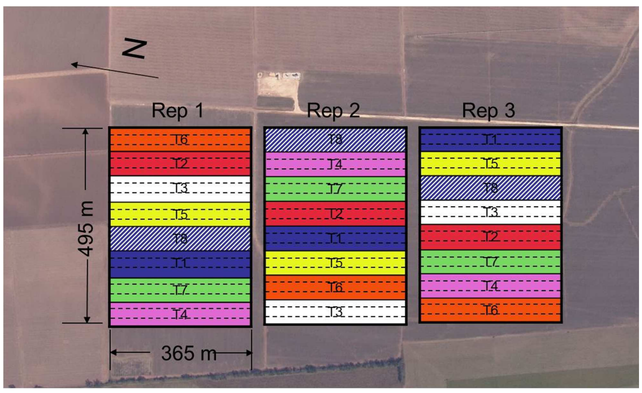

Figure 1. *Field layout of treatments and replications for Headline fungicide study, Burleson County, Texas.*

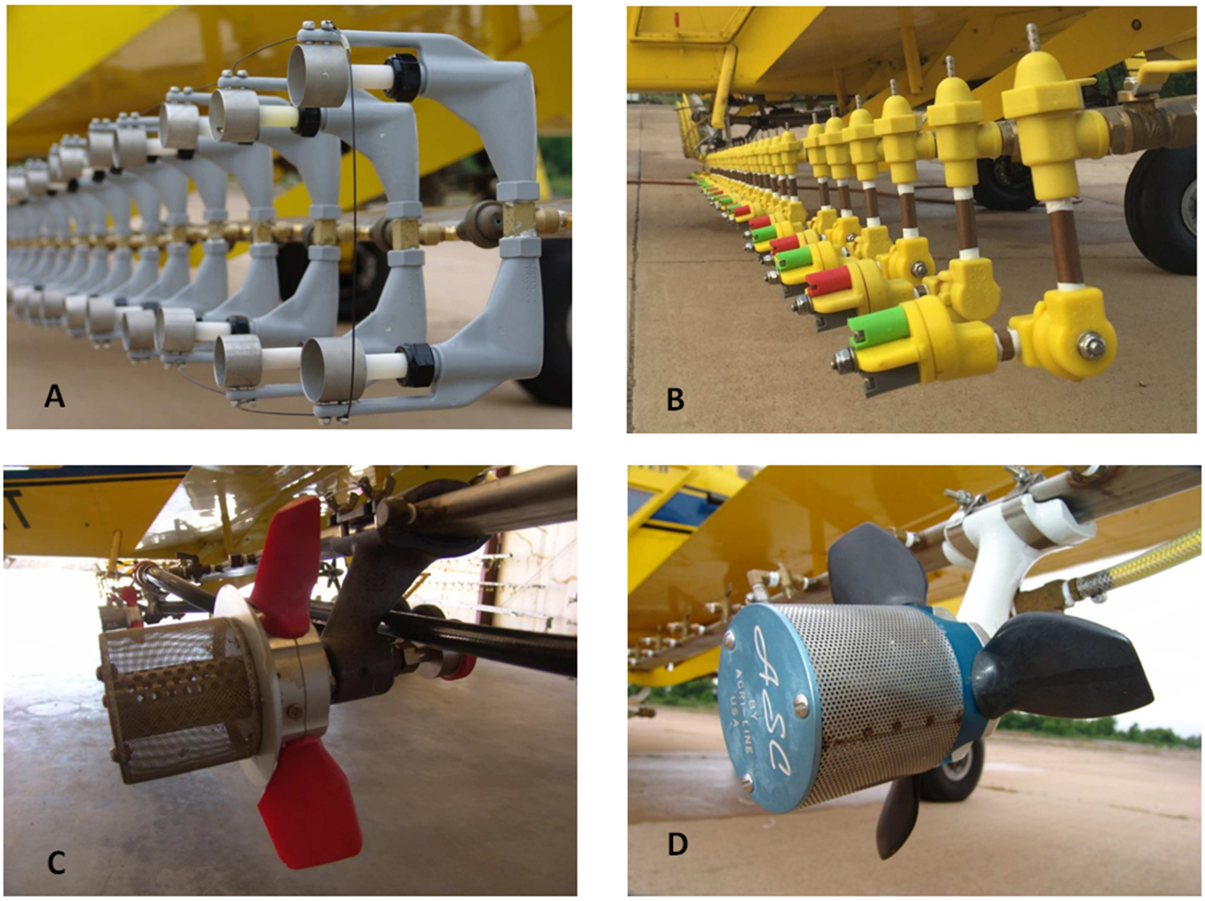

Figure 2. *Photographs of electrostatic nozzles (A), CP11-TT nozzles (B), AU5000 rotary nozzle (C) and ASC rotary nozzle (D).*

Table 1. *Application treatment operational parameters.*

Treatment [a]	Nozzle	# Nozzles	Application L/ha	Orifice	Deflection (°)	Pressure (kPa)	Airspeed (km/h)
E-1	Electrostatic[b]	100	10	TX-VK8	0	483	209
CP-1	CP-11TT[c]	21	10	4008	90	310	209
CP-2	CP-11TT[c]	39	19	4008	90	345	204
M-2	AU-5000[e]	8	19	VRU[f]=13	60	276	193
A-2	ASC Rotary[d]	6	19	D12	#4	145	193
M-1	AU-5000[e]	8	10	VRU=11	60	172	193
A-1	ASC Rotary[d]	6	10	D8	#4	145	193

[a] Treatment abbreviations define nozzles and spray rates, where 1 and 2 are 10 and 19 L/ha, respectively.
[b] Spectrum Electrostatic Sprayers, Houston, TX.
[c] CP Products Company, Tempe, AZ.
[d] Curtis-Dyna-Fog Ltd., Westfield, IN.
[e] Micron Sprayers Ltd., Herefordshire, UK.
[f] Variable Restrictor Unit which regulates the flow rate.

Table 2. *Meteorological data during aerial applications of Headline fungicide.*

Treatment [a]	In-wind (m/s)	Crosswind (m/s)	Mean Temp. (°C)	Mean RH (%)
E-1	3.22	0.30	28.5	74.8
CP-1	2.83	0.38	29.5	72.2
CP-2	2.72	0.44	30.3	68.3
M-2	2.36	1.00	32.2	59.4
A-2	2.36	0.61	32.7	59.2
M-1	3.27	0.50	32.8	57
A-1	2.30	0.42	32.4	59.1

[a] Treatment abbreviations define nozzles and spray rates, where 1 and 2 are 10 and 19 L/ha, respectively.

2.2. Data Collection of Spray Deposits

Deposition efficiency of the treatments on corn foliage was assessed using artificial and natural samplers. Artificial collectors comprised of a Mylar plate (100 x 100 mm) and a water sensitive paper (WSP) (26 × 76 mm; Spraying Systems Co., Wheaton, Ill.). A piece of corn leaf blade or lamina (2.54 cm in length) as a sample unit was the natural collector of deposits. Mylar plates and WSP samplers were placed horizontally on a single plate attached to a metal stake driven into the ground with a dowel rod extension. Five of each artificial sampler was placed at the tassel and ear leaf positions to assess deposition in the top and bottom canopy regions, respectively, in each replication in each treatment. These artificial collectors were removed 5 min. after each spray application and were placed in 35 mm negative sleeves and zippered plastic bags accordingly. Two pieces of the corn leaf blade, each ca. 15 to 20 cm long and 5 to 6 cm wide, were removed with scissors from horizontally oriented foliage in top and mid canopy regions in each replication and in each treatment. They were placed individually in sample bags and were kept in coolers to preserve the integrity of the samples. Upon completion of the test, all samples were transported to the laboratory for analysis.

2.3. Data Processing and Analysis

The WSP samples were processed with a computerized image analysis system (IMAQ Vision Builder V.5, National Instruments, Austin, TX) to obtain droplet stain density and stain size. Stain size, diameter and minimum dimension were determined from three 0.75 cm^2 sample areas on each card. Each stain in the sample area was converted to droplet diameter with an experimentally determined spread factor using the USDA ARS System (droplet size=0.54*stain diameter-8.5x10-5* stain diameter). These data were used to calculate percentage of spray coverage, droplet size ($D_{v0.5}$), droplet density (drops/cm^2) and spray rate (L/ha). The $D_{v0.5}$ (VMD) is the volume median diameter where 50% of the spray volume or mass is contained in droplets smaller than this value.

The Mylar plates and the corn leaves were washed in 40 ml of pure ethanol and a 6 ml portion of each effluent was placed in a 12 x 75 mm borosilicate glass culture tube. The cuvettes were then read by a spectrofluorophotometer (Shimadzu, Model RF5000U, Kyoto, Japan) with an excitation wavelength of 453 nm and an emission at 488 nm. The fluorometric readings were converted to µg of dye/cm². The fluorometric readings for each corn leaf sample was adjusted after determining the area of the leaf in cm^2 using a leaf area meter, LI-COR 3100® (Lincoln, NE).

2.4. Data Analysis

Data were analyzed using PROC GLM procedure using SAS version 9.4 [31]. When F-values were significant (P = 5%), means were separated using Duncan's Multiple range Test at P = 5%. The untreated check data was not included in the variance analysis because no disease was present during the study.

3. Results

3.1. Deposition on Water Sensitive Paper

The $D_{v0.5}$ of the spray droplets varied significantly between application methods in both top and mid-canopy positions (F = 13.86; df = 6, 96; P < 0.0001 for top canopy and F = 18.79; df = 6, 97; P < 0.0001 for mid canopy). The VMD at 19 L/ha for the AU5000 rotary atomizer was significantly larger than those for other application methods in the top canopy, regardless of carrier volume (Table 3). The $D_{v0.5}$ at 10 L/ha for the hydraulic nozzle was comparable to that for the electrostatic nozzles. The VMD at 19 L/ha for the AU5000 rotary atomizer was significantly larger than that for the ASC rotary atomizer at similar spray rate, but the VMD at 10 L/ha for the two atomizers was comparable.

Table 3. *Spray deposit measurements (Mean ± SEM) from water sensitive paper samplers on top canopy.*

Treatment [a]	Droplet size [b]	Droplet density [b]	Coverage [b]	Deposition [a]
	$D_{v0.5}$, µm	(#/cm^2)	(%)	(L/h)
E-1	182.0 ± 4.2d	54.4 ± 11.4a	1.43 ± 0.3bcd	4.41 ± 0.8bcd
CP-1	196.8 ± 7.5cd	21.4 ± 2.5b	0.58 ± 0.06d	1.83 ± 0.18d
CP-2	215.0 ± 7.38bc	71.4 ± 13.9a	2.17 ± 0.35b	7.25 ±1.24b
M-2	254.6 ± 7.9a	62.8 ± 10.7a	3.25 ± 0.69a	11.85 ± 2.66a
A-2	218.8±10.21b	45.2±10.5ab	1.75±0.48bc	6.05 ± 1.74bc
M-1	195.7±3.29cd	26.3±4.37b	0.74±0.1cd	2.34 ± 0.34cd
A-1	179.5 ± 5.75d	24.1 ± 5.6b	0.62 ±0.14d	1.87 ± 0.44d

[a] Treatment abbreviations define nozzles and spray rates, where 1 and 2 are 10 and 19 L/ha, respectively.

[b] Means within each column followed by the same lower case letter are not significantly different according to Duncan's Multiple Range Test (P<0.05).

The variations in droplet size in the mid canopy between application methods followed a pattern similar to those in the top canopy (Table 4). The $D_{v0.5}$ in the mid canopy for the AU5000 rotary atomizer at 19 L/ha was significantly larger than those for other application methods, regardless of carrier volume. The VMD at 10 L/ha for the hydraulic nozzle was essentially similar to that for the electrostatic nozzle. At 19 L/ha, the AU5000 rotary atomizer produced significantly larger droplets than the ASC rotary atomizer, but at 10 L/ha, the droplet size between the two rotary atomizers did not significantly differ from each other.

Table 4. *Spray droplet characteristics on water sensitive paper samplers in mid canopy (Mean ± SEM).*

Treatment [a]	Droplet size, $D_{v0.5}$, μm [b]	Droplet density [b] (#/cm^2)	Coverage (%) [b]	Deposition [b] (L/ha)
E-1	170.1 ± 3.7d	19.1 ± 2.6ab	0.52 ± 0.08bc	1.5 ± 0.25b
CP-1	171.1 ± 4.7d	11.4 ± 1.7bc	0.26 ± 0.04c	0.77 ± 0.14b
CP-2	188.3 ± 5.2c	24.4 ± 4.3a	0.77 ± 0.17b	2.41 ± 0.58b
M-2	231.3 ± 6.8a	27.6 ± 6.4a	1.46 ± 0.37a	5.20 ± 1.35a
A-2	204.1 ± 4.9b	11.0 ± 1.5bc	0.45 ± 0.06bc	1.50 ± 0.22b
M-1	182.2 ± 4.3cd	8.1 ± 1.4c	0.24 ± 0.04c	0.75 ± 0.12b
A-1	177.3 ± 5.3cd	7.1 ± 1.5c	0.20 ± 0.04c	0.61 ± 0.11b

[a] Treatment abbreviations define nozzles and spray rates, where 1 and 2 are 10 and 19 L/ha, respectively.

[b] Means within each column followed by the same lower case letter are not significantly different according to Duncan's Multiple Range Test (P<0.05).

The droplet density in both top and mid-canopy positions varied significantly between application methods (F = 4.61; df = 6, 96; P> 0.0004 for top canopy and F = 6.14; df = 6, 97; P<0.0001 for mid canopy). At 19 L/ha, the droplet density for the AU5000 and ASC rotary atomizers and the hydraulic nozzle in the top canopy did not vary significantly from one another. Nevertheless, droplet density for the electrostatic nozzle at 10 L/ha was comparable to those for the AU5000 and the ASC rotary atomizers and hydraulic nozzles at 19 L/ha. The droplet density at 10 L/ha for the AU5000 and the ASC rotary atomizers and the hydraulic nozzle was comparable.

The droplet density in the mid canopy for the AU5000 rotary atomizer at 19 L/ha was comparable to that for the hydraulic nozzle at similar carrier volume. Droplet density for the electrostatic nozzle at 10 L/ha did not significantly differ from those for the AU5000 atomizer and the hydraulic nozzle at 19 L/ha. All application methods at 10 L/ha produced comparable droplet density.

Spray coverage in top and mid canopy positions varied significantly between treatments (F = 7.32; df = 6, 96; P< 0.0001 for top canopy and F = 7.60; df = 6, 97; P< 0.0001 for mid canopy). The % coverage at 19 L/ha for the AU5000 rotary atomizer in the top canopy was the highest among application methods. The % coverage at 19 L/ha for the AU5000 rotary atomizer was 1.5 times higher than that for the hydraulic nozzle at the similar spray rate. The % coverage for the AU5000 rotary atomizer at 19 L/ha was 2-fold higher than that for the ASC rotary atomizer at similar carrier volume. Droplet density was comparable across application methods comprised of conventional nozzle, ASC and AU5000 rotary atomizer nozzles at 10 L/ha.

Spray coverage in the mid-canopy for aerial application methods was essentially similar to that in the top-canopy with few exceptions. Spray coverage for the AU5000 rotary atomizer at 19 L/ha predominated over all other application methods. The AU5000 atomizer at 19 L/ha produced 2-fold increased coverage compared to the hydraulic nozzle at the similar spray rate. The electrostatic nozzle at 10 L/ha spray rate produced spray coverage comparable to those for the hydraulic and ASC rotary atomizer at 19/L spray rate. The AU5000 rotary atomizer at 19 L/ha produced 3-fold increased coverage compared to the ASC rotary atomizer at similar spray rate.

Deposition in L/ha in the top and mid canopy regions was significantly different between treatments (F = 7.48; df = 6, 96; P < 0.0001 for top canopy and F = 7.85; df = 6, 97; P < 0.0001 for mid canopy). Deposition at 19 L/ha for the AU5000 rotary in the top canopy was significantly higher than those for all other application methods, regardless of carrier volume. Deposition at 10 L/ha for the electrostatic nozzle was comparable to that for the hydraulic nozzle at 19 L/ha. Deposition at 19 L/ha for the AU5000 rotary atomizer was twice as much as that for the conventional nozzle and the ASC rotary atomizer at the same spray rate. Deposition was comparable across all application methods at 10 L/ha comprised of electrostatic and conventional nozzles, ASC and AU5000 rotary atomizers.

Deposition for the AU5000 rotary atomizer in the mid canopy was significantly higher than those for all other application methods, regardless of carrier volume. Deposition for the AU5000 rotary atomizer at 19 L/ha was twice as much as that for the hydraulic nozzle at the same spray rate. Deposition for the electrostatic nozzle at 10 L/ha was comparable to that for the hydraulic nozzle at 19/L/ha. Deposition for the AU5000 rotary atomizer at 19 L/ha was 3.5-fold greater than that for the ASC rotary atomizer at the same rate. All application methods comprised of electrostatic and conventional nozzles and the rotary atomizers at 10 L/ha produced comparable deposition.

3.2. Deposit on Mylar Cards

Mylar deposit was significantly different between treatments in both top- and mid-canopy positions (F = 5.78; df = 6, 96; P<0.0001 in top canopy and F = 3.85; df = 6, 98; P> 0.0017 in mid canopy) positions. Deposition for the AU5000 rotary atomizer at 19 L/ha in the top canopy was significantly higher than those for other application methods, regardless of carrier volume (Figure 3). Also, the AU5000 atomizer at 19 L/ha received 7.5-fold increase in deposit compared to its counterpart at the lower spray rate. The AU5000 rotary atomizer at 19 L/ha spray rate received 3-fold increased deposition compared to hydraulic nozzle at the similar carrier volume. The electrostatic nozzle with 10 L/ha produced deposit essentially similar to that for the hydraulic nozzle at 19 L/ha. The AU5000 rotary atomizer at 19 L/ha received 5-fold increased deposit compared to the ASC rotary atomizer at the similar carrier volume.

The deposition portfolio in mid canopy was essentially similar to that in the top canopy (Figure 4).

Deposition for the AU5000 rotary atomizer at 19 L/ha was significantly higher than those for other application methods, regardless of carrier volume (Figure 4). Similar to that in the top canopy, the AU5000 rotary atomizer at 19 L/ha received 7-fold increased deposit compared to the lower carrier volume. The AU5000 rotary atomizer at 19 L/ha produced 3-fold greater deposit than the hydraulic nozzle at the same carrier volume. Deposit for the electrostatic nozzle at 10 L/ha was comparable to that for the hydraulic nozzle at 19 L/ha spray rate. The AU5000 rotary atomizer at 19 L/ha received 6-fold increased deposit compared to the ASC rotary atomizer at the similar carrier volume.

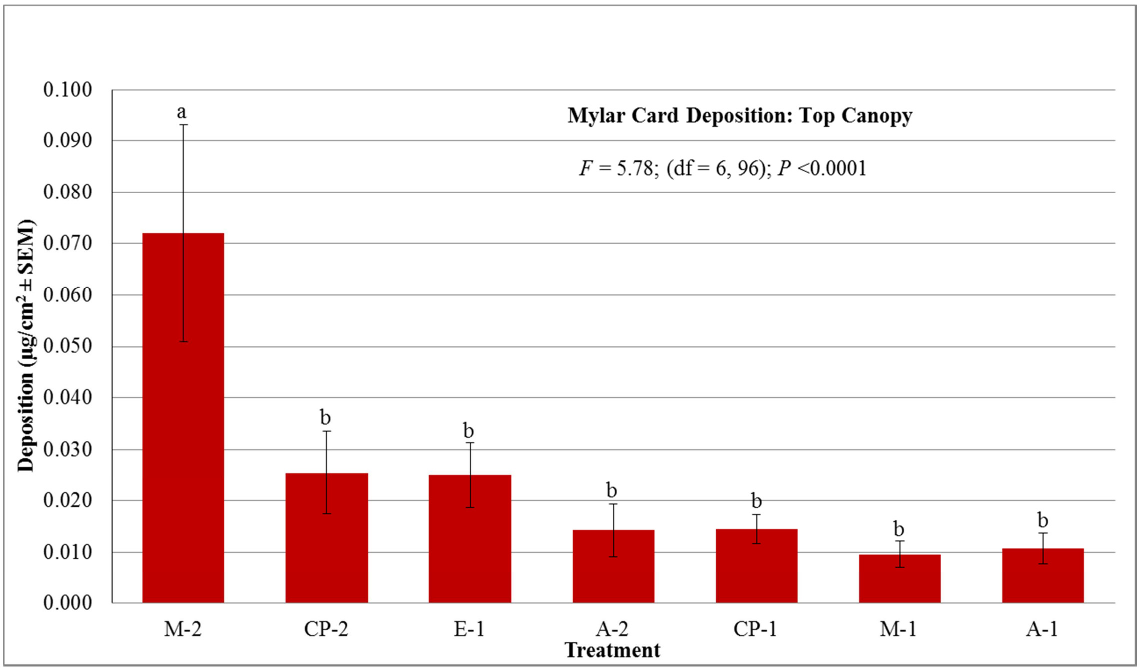

Figure 3. *Spray deposits of fungicide on Mylar cards placed in corn plant near the tassel (top canopy) in each of seven treatments. Treatment abbreviations define nozzles and spray rates, where 1 and 2 are 10 and 19 L/ha, respectively. Means with the same lower case letter are not significantly different (P < 0.05).*

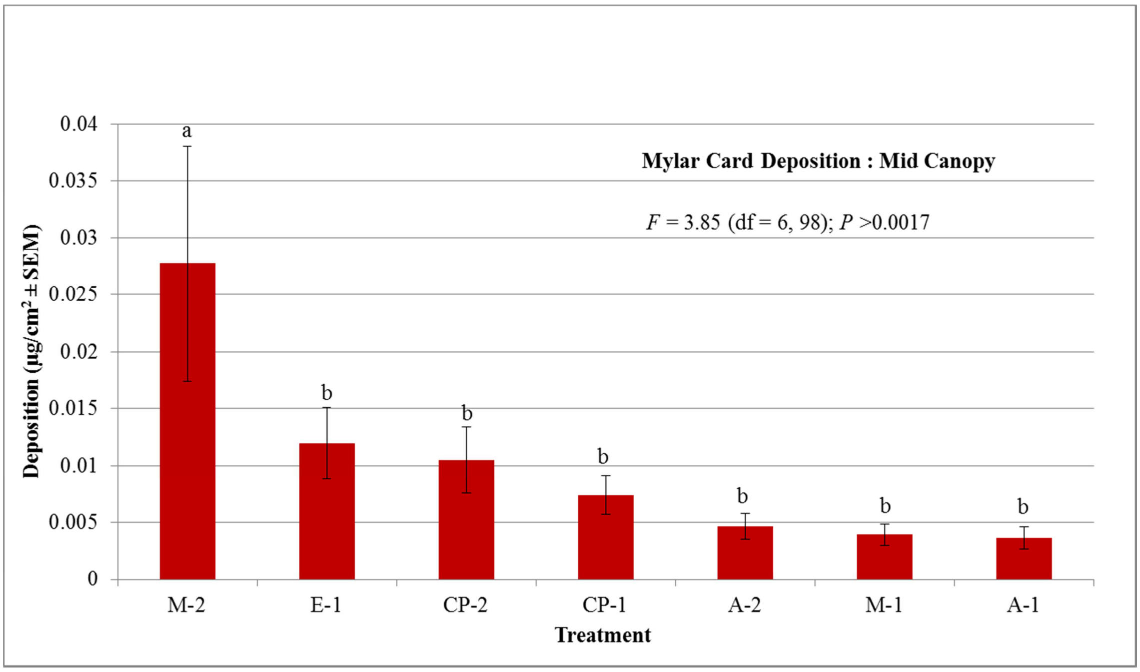

Figure 4. *Spray deposits of fungicide on Mylar cards placed in corn plant near the tassel (top canopy) in each of seven treatments. Treatment abbreviations define nozzles and spray rates, where 1 and 2 are 10 and 19 L/ha, respectively. Means with the same lower case letter are not significantly different (P < 0.05).*

3.3. Deposit on Corn Foliage

Mylar deposit on corn foliage significantly varied between treatments in both top and mid canopy positions (F = 6.38; df =6, 97; P< 0.0001 for top canopy and F = 5.63; df = 6, 96; P< 0.0001 for mid canopy). In the top canopy, deposition for the AU5000 rotary atomizer at 19 L/ha was significantly higher than those for other application methods, regardless of carrier volume (Figure 5). Deposition for the AU5000 rotary atomizer at 19 L/ha was 2-fold greater than that for the hydraulic nozzle at the similar carrier volume. Deposition for the electrostatic nozzle at 10 L/ha was not significantly different from that for the hydraulic nozzle at 19 L/ha spray rate, although the conventional nozzle received twice as much deposit as the electrostatic nozzle. The AU5000 atomizer at 19 L/ha received 5-fold increased deposit compared to the ASC rotary atomizer at the similar carrier volume.

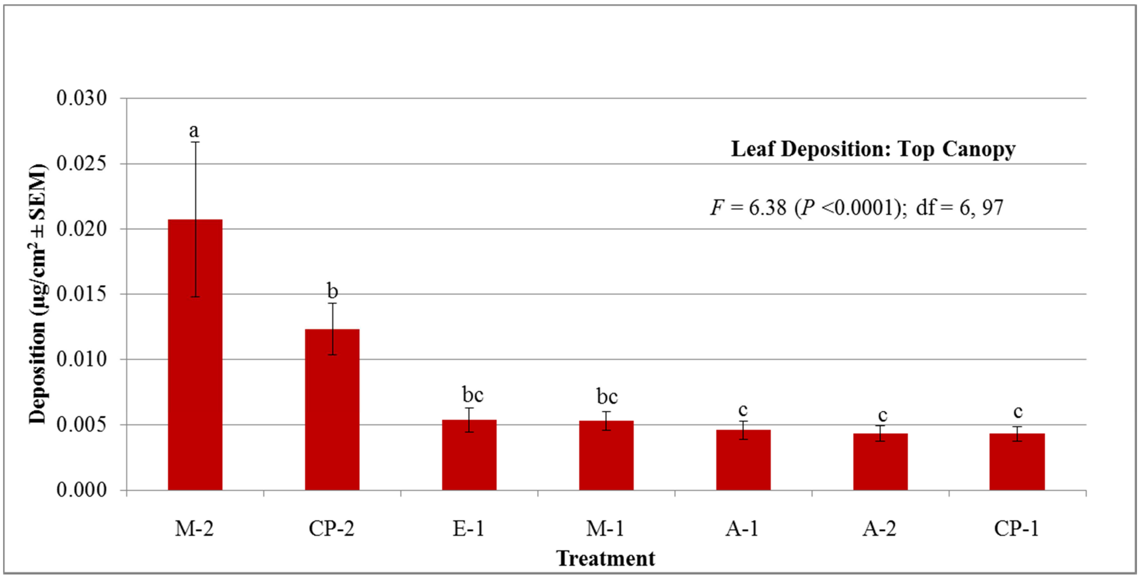

Figure 5. *Spray deposits of fungicide on Mylar cards placed in corn plant near the tassel (top canopy) in each of seven treatments. Treatment abbreviations define nozzles and spray rates, where 1 and 2 are 10 and 19 L/ha, respectively. Means with the same lower case letter are not significantly different (P < 0.05).*

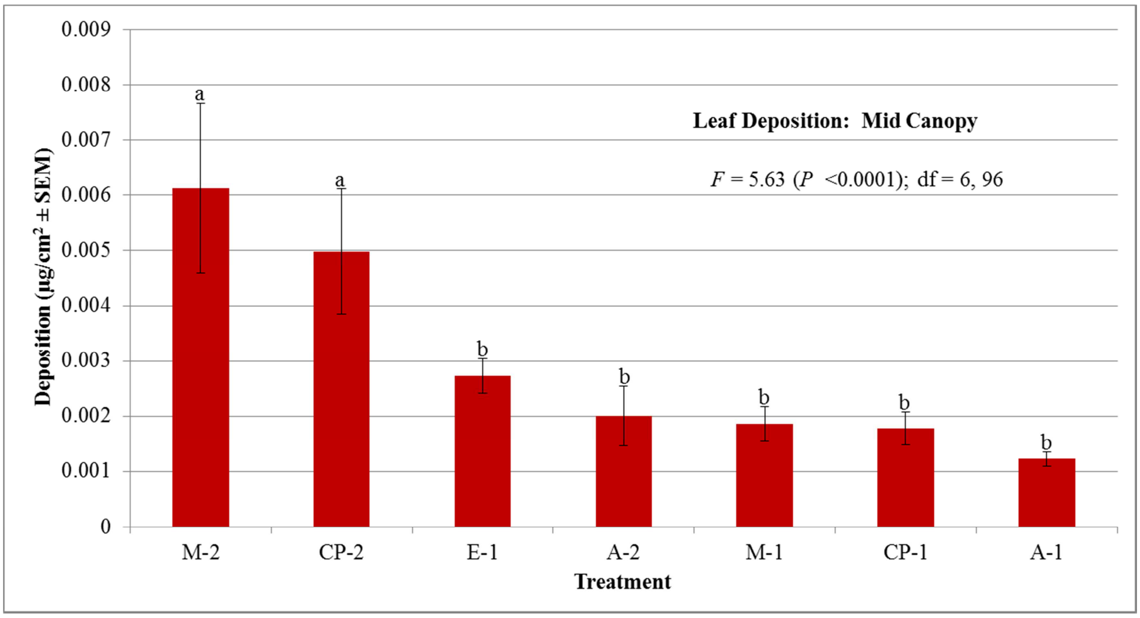

Figure 6. *Spray deposits of Headline fungicide on corn leaves near the tassel (top canopy) in each of seven treatments. Treatment abbreviations define nozzles and spray rates, where 1 and 2 are 10 and 19 L/ha, respectively. Means with the same lower case letter are not significantly different (P < 0.05).*

Contrary to the top-canopy, deposition for the AU5000 atomizer at 19 L/ha in the mid canopy was comparable to that for the hydraulic nozzle. The AU5000 atomizer at 19 L/ha received 3-fold increased deposit compared to the lower spray rate atomizer. The hydraulic nozzle at 19 L L/ha produced 2-fold increased deposit compared to the electrostatic nozzles at 10 L/ha spray rate (Figure 6). The AU5000 rotary atomizer at 19 L/ha received 3-fold increased deposit compared to the ASC rotary atomizer at the same carrier volume.

4. Discussion

Several studies have reported that optimum spray rate and droplet size combinations for aerially applied fungicides were pest specific and that it varied from one pest or target canopy to another. For instance, Fritz *et al*. [32] reported that CP-03 hydraulic nozzle at 18.7 L/ha and 350 µm droplet volume mean diameter was the optimal aerial spray treatment for fungicide deposition on wheat spikelets. Antuniassi *et al*.[33] reported that the aerial applications of fungicides with Miconair AU5000 and Stol ARD atomizers at 20 and 30 L/ha provided satisfactory control of soybean rust in Brazil. Bayer *et al*. [26] reported that the aerially applied fungicides on rice paddy with hydraulic nozzle at 20 and 30 L/ha and the electrostatic nozzle at 10 L/ha produced higher droplet density at the top 1/3rd of the leaf lamina, while the rotary disk atomizer produced higher droplet density in the middle and lower 1/3rd of the laminae. Based upon droplet spectra data produced by the AU5000 rotary atomizer mounted on an outdoor spray tower in Honduras, Washington [34] postulated that aerial applications of fungicides on banana with a droplet density ~ 30 droplets/cm^2 and a VMD between 300 and 400 µm would probably increase deposition while decreasing drift compared to finer droplets. Costa and Boller [35] reported that aerial sprays of fungicides on maize in Brazil with Microspin® rotary atomizers (similar to AU5000 Micronair) at 15 L/ha provided homogeneous distribution of spray droplets with a VMD near 175 µm. Fritz *et al*. reported that aerial applications with hydraulic nozzle at the higher spray volume and coarser droplet size on corn increased deposition on an artificial collector and corn silks compared to a lower volume and smaller droplet sprays [36].

The studies cited in this report include widely different botanical families comprised of maize, soybean and banana with divergent canopy characteristics. To illustrate the diversity in the canopy, it is suffice to say that the wheat spikelet is an inflorescence having flowers in a single, symmetrical spike while the corn leaf is a blade with an entire margin and thus these two collectors are structurally and morphologically different. Furthermore, researchers have reported that wind-induced turbulence within a crop canopy is likely to alter the shape, the stiffness and the geometric architecture of the vegetation such as wheat and corn whose canopy differ from each other in flexibility and roughness [37-39]. The results reported here suggest that the AU5000 rotary atomizer at 19 L/ha with a VMD near 255 µm and a droplet density ~ 63 droplets/cm^2 provided improved fungicide deposition on corn foliage compared to other application methods tested in the study and thus corroborating previous reports that aerial application methods to achieve optimum fungicide deposition did vary with crop canopy architectures. However, one of the limiting factors in using the rotary atomizer is the spray rate. The spray rate for the rotary atomizer should not exceed 46.8 L/ha because they are susceptible to flooding, and tend to restrict atomization of the droplets at the higher spray volume.

Researchers have reported that increasing spray rate alone did not increase deposition and penetration to the lower canopy since the upper plant canopy acted as a filter and retained most of the spray. It must be accompanied by adequate droplet distribution in order to improve penetration to the lower canopy [32, 40-43]. Barbosa et al. [44] reported that higher spray rates improved top and medium canopy deposition but did not improve lower canopy deposition in soybean when food colorant tartrazine was aerially applied as tracer. In this study, the AU5000 rotary atomizer at 19 L/ha did produce 7-fold increased deposit in the top and mid canopy positions compared to 10 L/ha in an artificial collector. Similar trend in increased deposition was evident on corn leaves as well for the AU5000 atomizer. Droplet density was also significantly higher in top and mid canopy positions as much as 2 to 3-fold for the AU5000 atomizer at 19 L/ha compared to lower carrier volume. Results demonstrate that the carrier volume did in fact significantly influenced deposition of fungicides on corn canopy.

A large body of research derived from computer modeling and field trials under different environmental conditions indicate that spray droplets ranging in size from 100 µm to 200 µm are driftable [45-51]. The percentage of spray volume made up of droplets less than 141 µm was a consistent index of spray drift that could be used either in aerial or ground-based applications of pesticides [52]. The droplet size generated by the rotary atomizer in this study is well within the cutoff value when you consider drift as a function of droplet size. In order to mitigate spray drift, additional steps such as increasing propeller blade angle of a rotary atomizer by 15 to 20° should slow the propeller and increase the droplet size by ca. 50 µm [53]. Recently, da Cunha *et al*. reported that the aerial application of thiomethoxam on soybeans using AU5000 rotary atomizers at 65° and 55° deflection angles significantly reduced drift compared to hydraulic nozzles [54].

The droplet spectra of aerially applied pest control materials using rotary atomizers primarily influences deposition and efficacy against pest organisms [27, 55, 56]. Drop size distribution produced by rotary atomizers can be modified through changes in pressure and flow rate [57], but it was largely influenced by the rotational speed of the nozzle [58]. Pesticide formulation characteristics such as viscosity and surface tension were also important in determining the droplet distribution [59-61]. Hoffmann *et al*. [62] reported that the spray adjuvants of pyraclostrobin fungicide also influenced droplet spectra distribution for the AU5000 rotary atomizer. Based upon a wind tunnel data base, Teske *et al*. [30, 63] reported that the aircraft speed, flow rate and atomizer rotation rate can greatly influence drop size distribution and deposition variability in aerial application methods using the AU4000 and AU5000 rotary atomizers. At higher flow rates and lower airspeeds, rotation rates were slower and the sprays were therefore coarser. Higher airspeeds caused more air shear across the atomizer, which produced finer sprays. Tank mix containing solutions with varying viscosity and surface tension largely influenced atomization and droplet size more than the flow rate. These data indicate that wind tunnel assessment of the droplet spectra for the AU5000 and the ASC rotary atomizers at different airspeed, blade angle, flow rate, rotation rate, surface tension and viscosity should help us understand the difference between these atomizers relative to deposition of aerially applied materials.

The results of this study support the previous findings by several researchers that the electrostatic system increased spray deposits on artificial targets and many cropping systems. For instance, Law and Lane [64] reported that electrostatically charged sprays increased deposition as much as 2 to 4-fold on broccoli, cabbage and corn compared to conventional spray applications. Franz [65] and Maski and Durairaj [66] reported that electrostatically charged aqueous sprays increased deposits on artificial targets compared to uncharged targets. Kirk *et al*. reported that spray deposits on cotton with aerially applied electrostatic system was higher than with conventional applications [67]. In this study, electrostatically charged spray applications produced deposits on an artificial collector as well as on corn foliage comparable to conventional applications. The only exception was in the mid canopy where deposition on corn leaves was significantly higher for the conventional nozzle than that for the charged spray application. Droplet density, % coverage and deposition on WSP samplers were comparable in both application methods. It is important to note that the increased deposits with the electrostatic system did not always translate into improved pest control [67].

5. Conclusions

The development of aerial application technologies to control foliar diseases is critical to maintain and advance increased corn grain yield in the United States. This study investigated aerial application methods for maximizing fungicide deposition on field corn. The aerial application of fungicides with AU5000 rotary atomizers at 19 L/ha and a volume median diameter ~ 255 µm provided the best fungicide deposition on mature field corn. These findings will help guide aerial applicators and corn producers in the selection of optimum aerial application parameters for maximum deposition of fungicides to combat foliar diseases on corn.

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Disclaimer

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