Aerial Application Methods for Increasing Spray Deposition on Wheat Heads

B. K. Fritz, W. C. Hoffmann, D. E. Martin, S. J. Thomson

Abstract. *Fusarium head blight (FHB) is a major disease of wheat and barley in several small grain production areas in the United States and, as such, the development and evaluation of aerial application technologies that enhance the spray deposition of fungicides, is critical to its management. This research was initiated to assess aerial spray technologies in an effort to increase spray deposits on wheat heads. Conventional hydraulic nozzles at two spray rates and two droplet sizes along with rotary atomizer and electrostatic treatments were investigated. Based on results from collectors and visual analysis the optimal spray treatment for deposition on wheat heads was hydraulic nozzles at 18.7 L/ha and a 350-μm droplet volume mean diameter. The results from this study provide guidance for aerial fungicide applications for increased deposition on wheat heads.*

Keywords. *Aerial application, Aerial spraying, Spray deposition, Fusarium head blight.*

Fusarium head blight (FHB) is a major disease of wheat and barley in several small grain production areas in the United States. By the mid-1990s, cultural practices, resistant cultivars, and fungicides had made only limited progression on managing the disease (Parry et al., 1995). Recent studies on fungicide application efficacy have focused on biological responses to fungicides and have not considered the importance of application parameters such as spray pressure, spray rate, and associated spray droplet spectra (Milus and Parsons, 1994; Shaner and Buechley, 1999; Milus et al., 2001; Hershman and Milus, 2002). Halley et al. (1999) evaluated two ground application systems with varying nozzle orientations and water volumes for increased deposition of fungicide on grain spikes and found that nozzles oriented in alternating front-angled and back-angled positions significantly increased deposition and disease management. Droplet size of spray was not examined or reported. Both Halley et al. (1999) and Hart et al. (2001) showed the importance of thorough coverage of the wheat heads as a factor in fungicidal efficacy for FHB suppression emphasizing the need for optimizing application parameters such that maximum deposition is achieved.

Numerous studies have been reported on optimization of aerial application practices for pest control in cotton, corn, and weed and brush control, noting that optimum spray rate droplet size combinations are pest specific and vary from one pest or target area to another (Bouse et al., 1992; Hoffmann et al., 1998; Kirk et al., 1989, 1992, 1998 and 2001). Kirk et al. (1989) found that higher spray rates with smaller droplet volume mean diameters (VMDs) resulted in increased herbicide deposits on yellow foxtail plants. Bouse et al. (1992) found that increased spray rates and decreased droplet VMDs resulted in increased mortality of honey mesquite. Kirk et al. (1992) found that higher spray rates and larger droplet VMDs resulted in increased deposits within the canopy of cotton plants. Hoffmann et al. (1998) found that smaller droplet VMDs and lower spray rates resulted in increased levels of control for the targeted insect pest.

Previous research completed by the College Station USDA-ARS Aerial Application research group directly addressed this issue. Kirk et al. (2004) focused on applications with conventional hydraulic nozzles as well as rotary atomizers at spray rates ranging from 94 to 2 L/ha and droplet VMDs from 230 to 415 μm. Kirk et al. (2004) found that rotary atomizers at 47 L/ha with smaller droplet VMDs (240 μm) resulted in maximum deposition on wheat heads and mylar collectors. A follow-up up study performed the next year over three separate fields examined treatments applied with conventional hydraulic nozzles with flow rates of 19, 47, and 94 L/ha and droplet VMDs of 175 and 350 μm (Fritz et al., 2005). The results showed highest deposition amounts at the lowest spray rates with larger droplet VMDs (Fritz et al., 2005).

Objective

This study was conducted to assess and characterize spray deposition on wheat heads using optimum spray rate and droplet size combinations from previous studies and alternative application technologies in field conditions in an effort to optimize aerial application techniques for maximum deposition on wheat heads.

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Materials and Methods

Six aerial application methods were selected for testing spray deposition on wheat heads. The wheat field used in the study was near College Station, Texas (30°32'39.24"N 96°27'26.98"W). The experimental design was a randomized complete block with six levels of spray treatment. Each treatment was replicated three times. Sampling was conducted at two locations within each treatment block (fig. 1). For each plot, five 15-m swaths were applied over a plot length of 380 m resulting in a total area sprayed for each plot of 3.8 ha. Hydraulic nozzles and rotary atomizer treatments were based on previous work (Kirk et al., 2004; Fritz et al., 2005). For the conventional hydraulic nozzle treatments, CP-03 nozzles were selected (CP Products Company, Inc., Tempe, Ariz.). The rotary atomizers used were ASC-A10H Atomizers (Curtis Dyna-Fog Ltd., Westfield, Ind.). The electrostatic nozzles were solid-body nozzles from Spectrum Electrostatic Sprayers, Inc (Houston, Tex.).

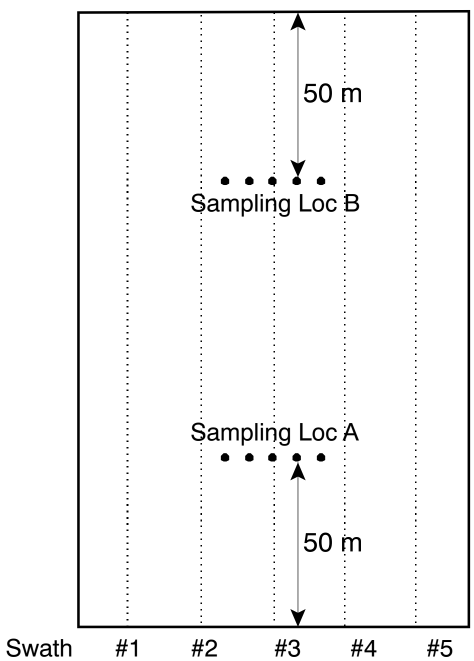

Figure 1. Layout of sampling locations within each treatment/replication plot.

Spray performance variables were documented based on *ASAE Standards* (1999, 2001). These standards define $D_{V0.5}$, Droplet Spectra Classification (DSC) and other pertinent spray parameters. The treatments and their respective spray rates, $D_{V0.5}$, and droplet size classifications (DSC) are shown in table 1. The volume median diameter, $D_{V0.5}$, is the diameter such that 50% of the total volume of droplets is in droplets of smaller diameter. The $D_{V0.5}$ for each CP-03 nozzle treatment was determined using the Aerial Applicators Spray Nozzle Handbook (USDA-ARS AH-726) and the nozzle and aircraft operating parameters. Droplet spectra data for the rotary atomizers and electrostatic nozzles treatments were determined in a wind tunnel equipped with a Particle Measurement System laser diffraction device. The aircraft used to apply the treatments was a turbine powered Air Tractor AT-402B (Air Tractor, Inc., Olney, Tex.) operated at airspeeds specified in table 1.

Water-based spray mixtures, for all treatments, contained equal per-hectare rates of the colorimetric tracer, FD&C Blue #1 food-grade dye mixed at 50 g/ha. No active ingredient (fungicide) was included in the tank mixture. Addition of active ingredients could potentially change spray characteristics and deposition patterns, though deposition trends among treatments would likely be similar. Weather parameters were monitored and recorded during all spray applications with a Gill 27005 Anemometer (R. M. Young Company, Traverse City, Mich.), a Young 43372VC Relative Humidity and Temperature Probe (R. M. Young Company, Traverse City, Mich.), and a Campbell 21-X data logger (Campbell Scientific, Inc., Logan City, Utah). Weather conditions varied between treatments, but remained relatively constant within individual treatments (table 2).

Data Collection, Processing, and Analysis

To avoid cross contamination between plots, sampling was done only from the center swath for each plot (i.e. swath #3). Artificial samplers were placed at each sampling site (A and B) at five equally spaced intervals (approx. 4 m) with the center position directly centered on the projected aircraft swath. Artificial samplers consisted of a mylar plate (100 × 100 mm) and a water sensitive paper (WSP) (26 × 76 mm). At each sampling location, one Mylar plate and one WSP was oriented horizontally at the top of the crop canopy.

Table 1. Application parameters and settings.

Trt	Nozzle	Notation[a]	Deflector Angle	Orifice (mm)	Spray Pressure (kPa)	Airspeed (km/h)	Spray Rate (L/ha)	$D_{V0.5}$ (μm)	DSC[b]
1	ASC rotary atomizers[c]	RA	--	--	276	241	18.7	175	VF
2	Spectrum electrostatics	ES	--	--	276	177	9.4	150	VF
3	CP-03	LVF	90°	3.2	414	241	18.7	179	VF
4	CP-03	HVF	90°	3.2	414	241	46.8	179	VF
5	CP-03	LMD	55°	3.2	414	161	18.7	350	M
6	CP-03	HMD	30°	3.2	414	161	46.8	350	M

[a] The notation column denotes the three letter notation that will be use throughout the manuscript, for treatment applied using CP-03 nozzles the first letter refers to the spray rate (H – high, 47 L/ha; and L - low, 19 L/ha) and the second letter refers to the droplet size spectrum (VF - very fine; and MD - medium). ASC - Rotary Atomizers. ES - Electrostatics.

[b] Defined by ASAE S572 AUG99 Droplet Spectra Classification; VF - VERY FINE and M - MEDIUM.

[c] Blade angle was set to the #7 mark resulting in 10,000 rpm fan speed, achieving the target droplet size of 175 μm.

Table 2. Mean weather conditions for each treatment/replication combination over wheat field near College Station, Texas.

Treatment	Replication	Mean Wind Velocity[a] (m/s)	Mean Temperature[a] (°C)	Mean Relative Humidity[a] (%)
1	1	0.8	19.5	56.8
1	2	0.7	20.5	56.4
1	3	0.4	20.7	52.7
2	1	4.3	27.8	29.3
2	2	4.1	27.8	30.0
2	3	3.2	27.8	29.6
3	1	2.3	23.8	44.1
3	2	3.1	23.9	40.5
3	3	3.3	23.9	41.2
4	1	4.2	24.9	36.6
4	2	3.9	25.0	37.5
4	3	3.5	25.2	39.9
5	1	3.8	25.9	35.0
5	2	3.4	26.0	35.1
5	3	5.2	25.8	32.6
6	1	4.2	26.5	31.3
6	2	3.8	26.7	32.8
6	3	2.8	26.7	31.8

[a] Mean values are representative time period associated with start of first spray pass and completion of final spray pass.

Following application of the final spray swath for a given location, all sampling media were collected. Wheat head samples (total wheat head cut where stalk meets head), comprised of 10 randomly chosen heads, were collected at each sampling location. Mylar samples at each sub-station were collected and bagged individually. For each plot, 10 Mylar samples (five from each site A and B), 10 wheat head samples (five from each site A and B), and 10 horizontal WSP samples (five from each location A and B) were collected and bagged separately. All samples were labeled with treatment, replication, sample, and sample information. All samples were placed into insulated coolers immediately after collection for transport to the laboratory for analysis. An additional 10 randomly chosen wheat heads from each sampling location were bagged, labeled, and stored for fluorescent photography.

Mylar plates and wheat head samples were washed in 20 to 40 mL of ethanol in the collection bags. A sample portion of the wash effluent was placed in a 12- × 75-mm borosilicate glass culture tube and colorimetric dye concentrations were obtained with a Pharmacia Ultrospec III spectrophotometer (Pharmacia LKB Biochrom Ltd., Cambridge, England). Spray deposits were quantified by comparison with similarly determined dye concentrations from spray tank samples and areas of the respective samples. Following washing, projected areas of the wheat head samples were determined with a LI-3100 Area Meter (LI-COR, Inc., Lincoln, Nebr.). The data quantifications were expressed as quantity of dye (μg) deposited per unit area of the sample (cm^2).

The WSP samples were processed with computerized image analysis (IMAQ Vision Builder v5, National Instruments, Austin, Tex.) to determine droplet stain density and stain size. Stain size, stain diameter, and minimum stain dimension were determined in two 0.75-cm^2 sample areas on each card. Each stain in the sample area was converted to droplet diameter with an experimentally determined (in-house) spread factor (Droplet Diameter = 0.54*stain diameter – 8.5×10^{-5}*stain diameter^2).

Fluorescent photos were taken by placing wheat heads in groups of five in a dark box with overhead black light and camera mount. Exposure speed was adjusted to maximize contrast between wheat head bodies and spray deposits. Sequential photographs were taken on opposing faces of the wheat heads. Photos were used for visual assessment of coverage.

Statistical analysis of deposition data on wheat heads and mylar plates was completed in SAS (Version 9.1) using PROC MIXED. For each set of sampler-specific data, analysis of variation in dye deposition was completed with Treatment and sample location as fixed effects. Random effects included Replication (Replication * Treatment), and (Replication * Location (A or B) within Treatment). Residual error included Replication*sample location within Treatment and Location (A or B). Statistical models were simplified by dropping out non-significant fixed effects. Otherwise, F-tests based on partial contributions could be misleading.

Results

Deposition on Water Sensitive Paper

The WSP samples were used to assess "as deposited" droplet size data for each treatment (table 3). Treatments based on a $D_{V0.5}$ of 175 μm resulted in overall measured $D_{V0.5}$s on the horizontally placed WSP ranging from 136 to 150 μm. On average the 175-μm treatments were 81% of the targeted size. The electrostatic treatment, $D_{V0.5}$ of 150 μm, resulted in an overall measured $D_{V0.5}$ of 140 μm; 93% of the targeted size. Treatments based on a $D_{V0.5}$ of 350 μm, resulted in overall measured $D_{V0.5}$s on the horizontally placed WSP ranging from 239 to 205 μm. On average the 350-μm treatments were 64% of the targeted size. The reduction in droplet size was likely due to low relative humidity resulting evaporative decrease of droplet sizes.

Deposits on Wheat Heads and Mylar Samplers

The least square mean deposition of dye on the Mylar and wheat head samples is given in table 4. There was a significant treatment effect ($P < 0.0001$) on deposition of dye on wheat heads. Application treatment LMD resulted in

Table 3. Aerial spray deposit VMD for water sensitive paper samples.

Treatment Number	Treatment Notation	VMD (μm)
1	RA[a]	150
2	ES[b]	140
3	LVF[c]	136
4	HVF[d]	141
5	LMD[e]	205
6	HMD[f]	239

[a] ASC Rotary Atomizers (RA) at 18.7 L/ha and 175 μm.
[b] Spectrum Electrostatics (ES) at 9.4 L/ha and 150 μm.
[c] CP-03 nozzles at 18.7 L/ha (L - Low) and 175 μm (VF - Very Fine).
[d] CP-03 nozzles at 46.8 L/ha (H - High) and 175 μm (VF - Very Fine).
[e] CP-03 nozzles at 18.7 L/ha (L - Low) and 350 μm (MD - Medium).
[f] CP-03 nozzles at 46.8 L/ha (H - High) and 350 μm (MD - Medium).

Table 4. Least square mean deposition of dye (µg dye/cm²) on Mylar and wheat head samples by treatment.

Treatment	Least Square Mean Deposition on Mylar (µg dye/cm^2)	Least Square Mean Deposition on Wheat Heads (µg dye/cm^2)
1	0.0165	0.0397
2	0.2058	0.3880
3	0.0940	0.2769
4	0.1043	0.2112
5	0.2709	0.5051
6	0.2465	0.2481

maximum deposition on wheat heads (table 5). Application treatments ES and LVF resulted in the next highest deposition amounts on the wheat heads. Application treatment RA resulted in the lowest deposition values. There was also a significant treatment effect ($P < 0.0001$) on deposition of dye on the mylar collectors (table 5). Application treatments LMD and HMD resulted in maximum deposition on mylar samplers. Applications treatment RA resulted in the lowest deposition amounts on the mylar cards.

Treatments are listed in order of decreasing dye deposition means. Factor levels joined by underline are not significantly different based on Duncan's multiple range test ($p = 0.05$).

Fluorescent Photography Results

Fluorescent photos of exposed wheat heads were taken in an effort to document the physical coverage resulting from each treatment. Figures 2 through 7 are images obtained from collected wheat heads for all six treatments. The figures show two representative wheat heads side-by-side from front and back faces (Sides A and B in pictures).

All treatments resulted in material being deposited on only one face of the wheat head. This observation was made by Kirk et al. (2004) based on results from WSP rolled into cylinders and place vertically in the sampling array. Kirk et al. (2004) observed that the face onto which the material was deposited was the side facing into the wind. Multi-pass spraying in opposing directions did not result in complete wheat head coverage (Kirk et al., 2004). Droplet deposition on upwind side of wheat heads is due to droplet momentum as a result of being transport in direction of wind causing impaction deposition. Visual coverage differences do not correlate to the mass of dye deposition differences on the wheat heads. Application from the LMD treatment (fig. 6) has visibly less coverage than application from HMD treatment (fig. 7) yet the LMD treatment resulted in maximum dye deposition on the wheat heads while the HMD treatment resulted in near minimum deposition (table 4). The active ingredient (in this case the added dye) is at a greater concentration per volume in the LMD spray solution than compared with the HMD spray solution. The ES treatments, while not having visibly greater coverage as compared to other treatments (fig. 3), did result in near maximum dye deposition amounts on the wheat heads (table 4).

Table 5. Results of testing for treatment effects on mean deposition on wheat heads and Mylar.

Sample	Significance	Separation of Means with Significance Links					
Wheat heads	$P < 0.0001$	LMD	ES	LVF	HMD	HVF	RA
Mylar	$P < 0.0001$	LMD	HMD	ES	HVF	LVF	RA

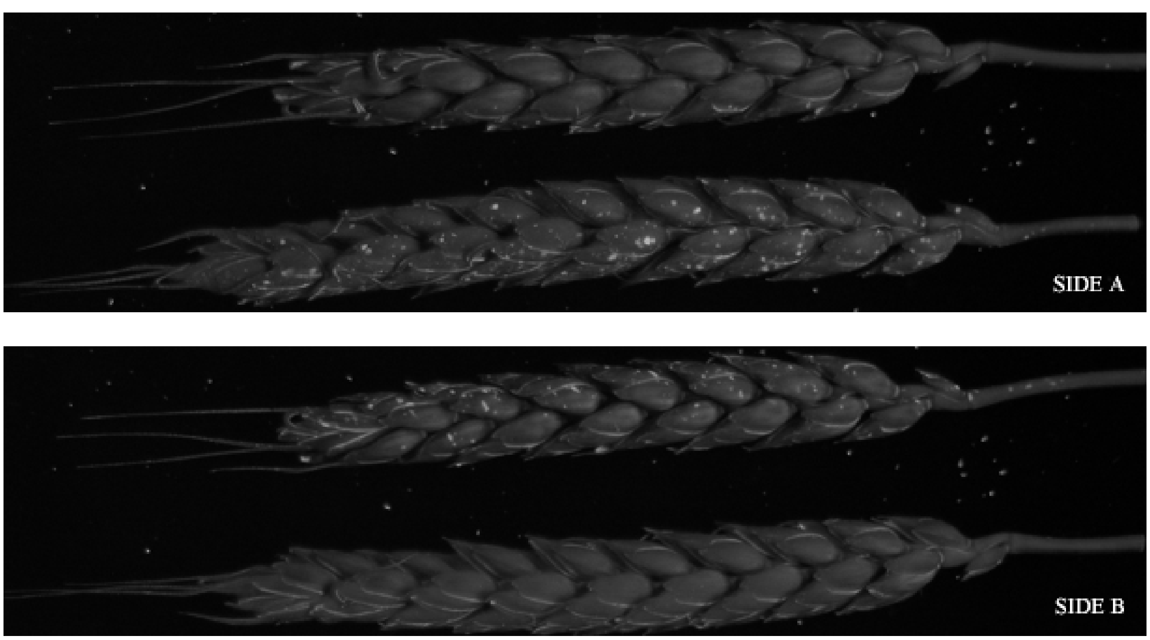

Figure 2. Photos obtained from both sides of collected wheat heads obtained from plots treated with Rotary Atomizers (Treatment 1 - Spray Rate of 18.7 L/ha and $D_{V0.5}$ of 175 µm). Top two images are face A and bottom two images are face B of same wheat heads.

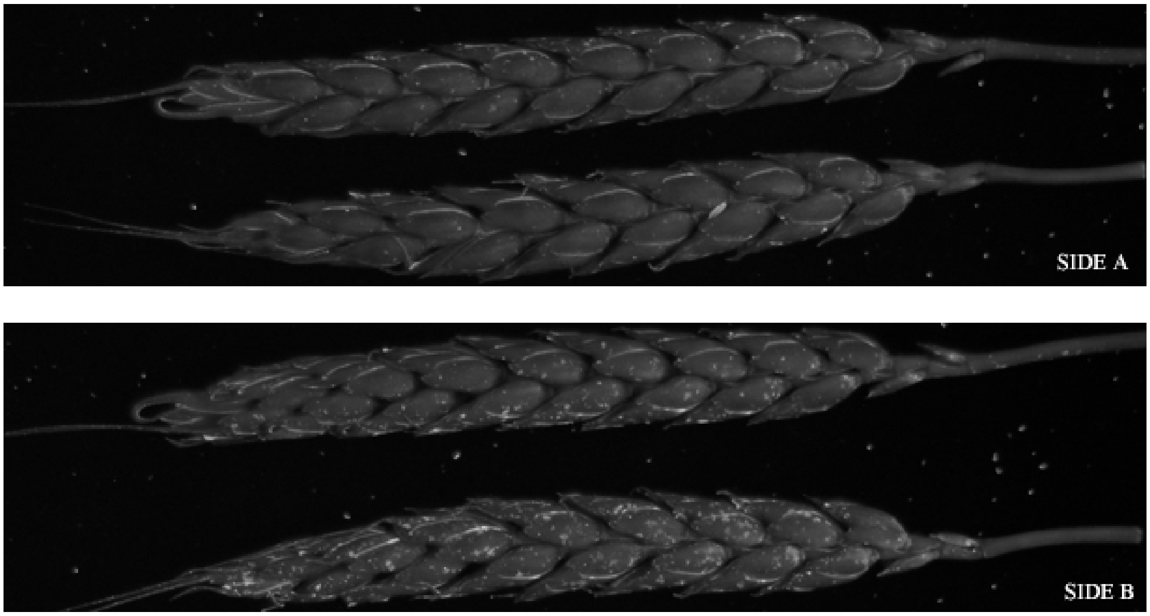

Figure 3. Photos obtained from both sides of collected wheat heads obtained from plots treated with Electrostatics (Treatment 2 - Spray Rate of 9.4 L/ha and $D_{V0.5}$ of 150 µm). Top two images are face A and bottom two images are face B of same wheat heads.

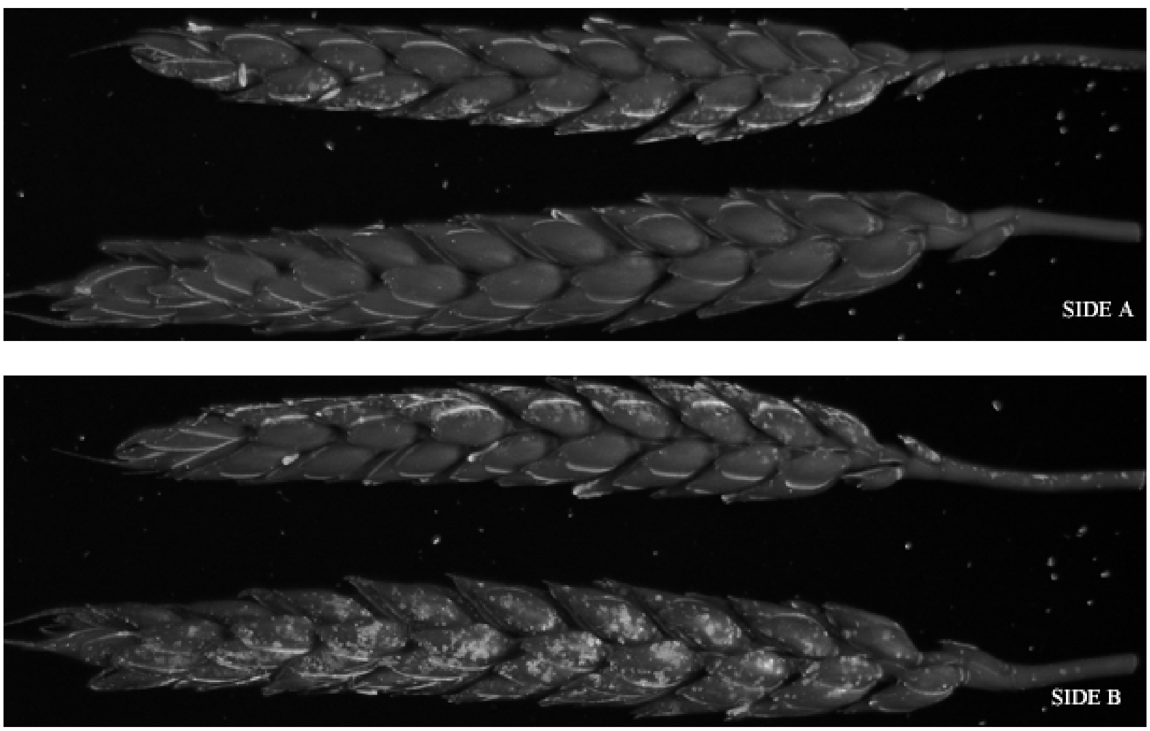

Figure 4. Photos obtained from both sides of collected wheat heads obtained from plots treated with CP-03 nozzles (Treatment 3 - Spray Rate of 18.7 L/ha and $D_{V0.5}$ of 175 µm). Top two images are face A and bottom two images are face B of same wheat heads.

CONCLUSIONS

This study was conducted to optimize aerial application technologies for enhanced spray deposition on wheat heads. Both conventional hydraulic technologies as well as electrostatic and rotary atomizer technologies were examined. Overall, hydraulic nozzles set up to apply at spray rate of 18.7 L/ha and a $D_{V0.5}$ of 350 µm resulted in maximum deposition on wheat heads. Electrostatics resulted in the next highest deposition amounts on the wheat heads. Higher volume applications resulted in near minimum deposition on wheat heads along with rotary atomizer applications. The hydraulic nozzle applications at the higher rates along with rotary atomizer applications resulted in minimum deposits on collected wheat heads. Fritz et al. (2005), while observing WSP measured droplet sizes closer to targeted size, showed the same trend of lower spray rates with larger droplet sprays resulting in maximum deposition was observed in both studies. A secondary benefit of the lower spray rate

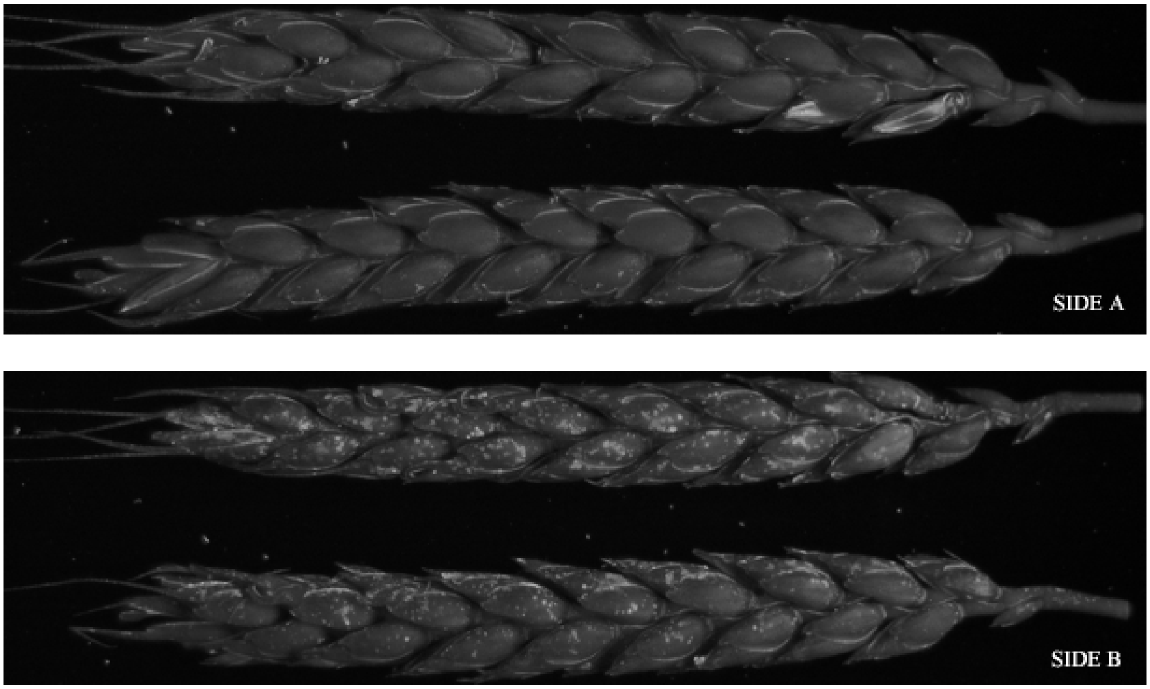

Figure 5. Photos obtained from both sides of collected wheat heads obtained from plots treated with CP-03 nozzles (Treatment 4 - Spray Rate of 46.8 L/ha and $D_{V0.5}$ of 175 µm). Top two images are face A and bottom two images are face B of same wheat heads.

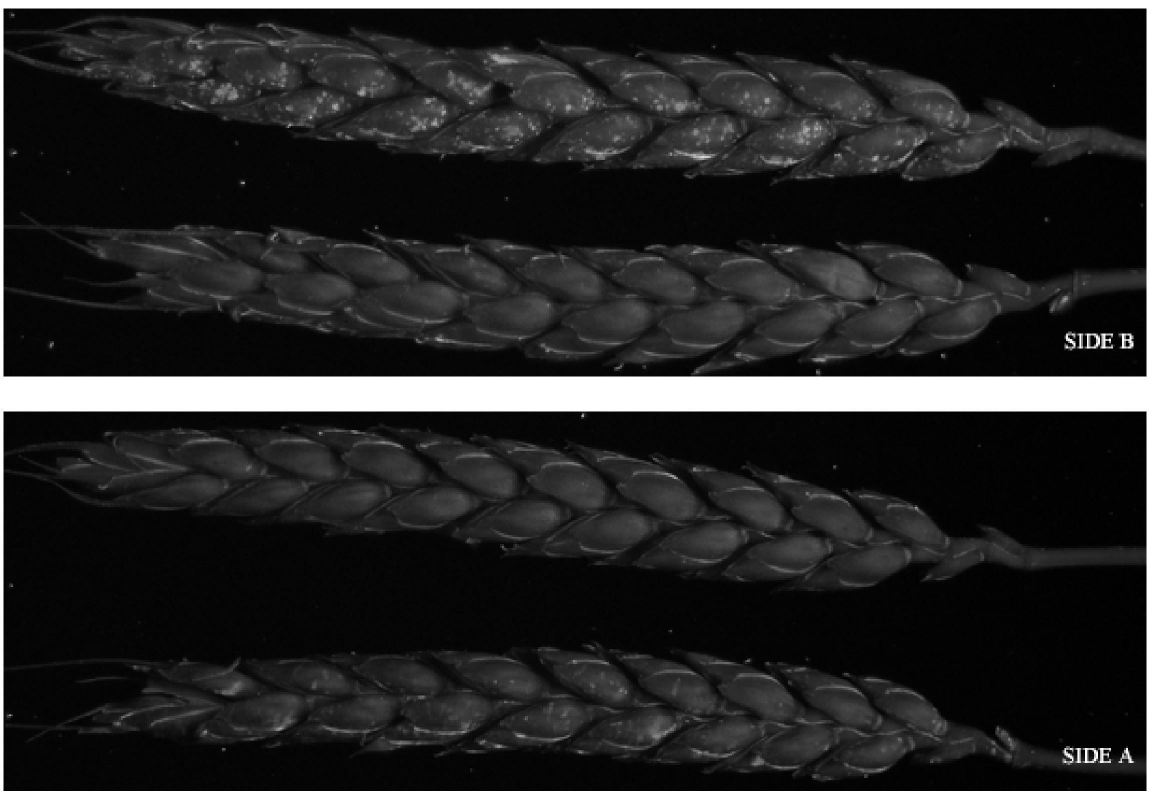

Figure 6. Photos obtained from both sides of collected wheat heads obtained from plots treated with CP-03 nozzles (Treatment 5 - Spray Rate of 18.7 L/ha and $D_{V0.5}$ of 350 µm). Top two images are face A and bottom two images are face B of same wheat heads.

treatments for applicators is increased productivity due to reduced loading and ferrying times. The optimal treatment setup of the hydraulic nozzles at 18.7 L/ha with a $D_{V0.5}$ 350 µm has less drift potential than the smaller-droplet treatments, and maximizes deposition of active ingredient on the spray target.

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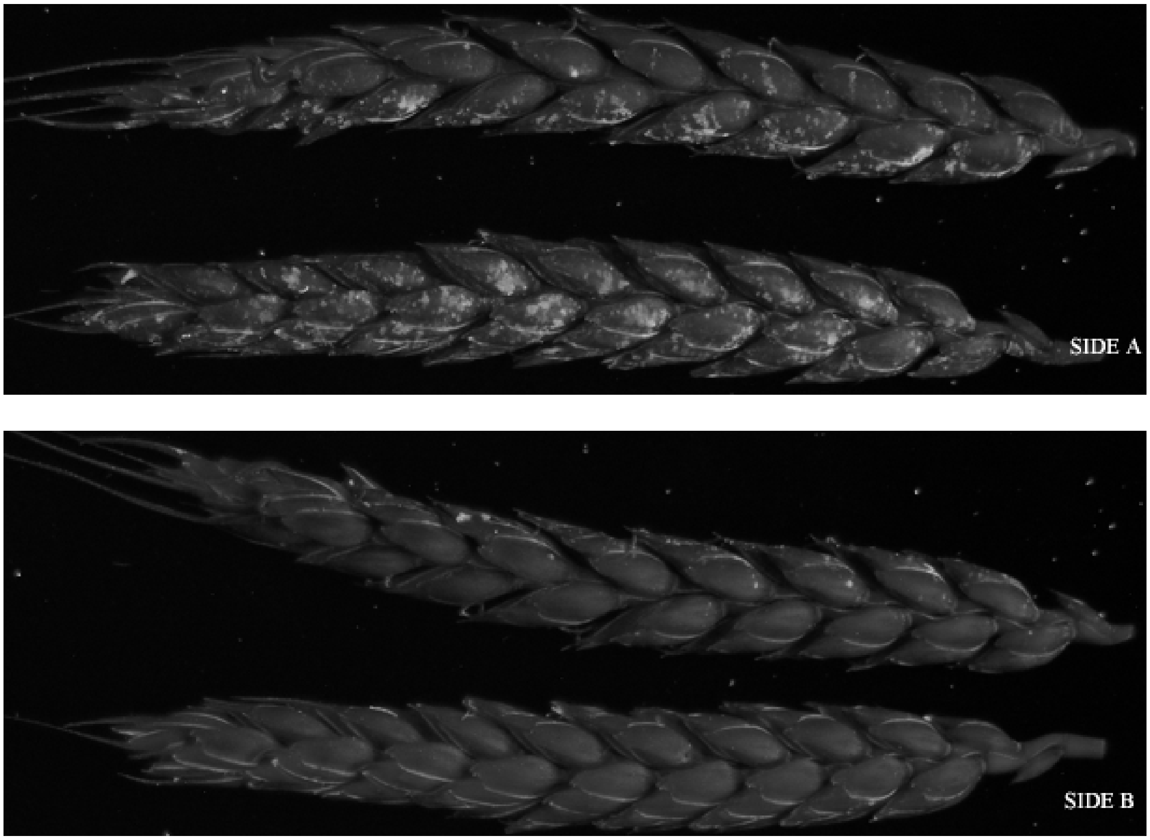

Figure 7. Photos obtained from both sides of collected wheat heads obtained from plots treated with CP-03 nozzles (Treatment 2 - Spray Rate of 46.8 L/ha and $D_{V0.5}$ of 350 µm). Top two images are face A and bottom 2 images are face B of same wheat heads.

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