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Aerial Application Methods for Increasing Spray Deposition on Wheat Heads

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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 efficacy of fungicides with aerial spray applications, is one of the research priorities of the United States Wheat and Barley Scab Initiative. This research was initiated to assess aerial spray technologies in an effort to increase spray deposits on wheat heads. Conventional hydraulic nozzles at two sprays 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 (2 gpa) and a 350 µm droplet size, which agrees with work done previously. The results from this study are expected to provide guidance for aerial fungicide applications for increased deposition on wheat heads.*

Keywords. Aerial application, aerial spraying, spray deposition, wheat head blight.

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Introduction

Fusarium head blight (FHB) is a major disease of wheat and barley in several small grain production areas in the U.S. By the mid 1990's, cultural practices, resistant cultivars, and fungicides had made only limited impact on managing the disease (Perry et al., 1995). Recent studies on efficacy of fungicide applications focus on fungicide type and not effects of application parameters such as spray pressure, spray rate and associated spray droplet spectrum (Milus et al., 2001; Hershman and Milus, 2002; Shaner and Buechley, 1999; and Milus and Parsons, 1994). Halley et al. (1999) evaluated two ground application systems with varying nozzle orientations and water volumes for deposition of fungicide on grain spikes and found that nozzles oriented in alternating front-angled and back-angled positions significantly increased deposition and control. Droplet size of spray was not examined or reported. Both Hart et al. (2001) and Halley et al. (1999) 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, weeds, and brush 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, and Kirk et al., 1989, 1992, 1998 and 2001). Kirk et al. (1989) found that higher spray rates with smaller droplet sizes resulted in increased herbicide deposits on yellow foxtail plants. Bouse et al. (1992) found that overall, increased spray rates and decreased droplet size resulted in increased mortality of honey mesquite. Kirk et al. (1992) found that higher spray rates and larger droplet sizes resulted in increased deposits within the canopy of cotton plants. Hoffmann et al. (1998) found that smaller droplet sizes 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 L/ha (10 gpa) to 18.7 L/ha (2 gpa) and droplet sizes from 230 µm to 415 µm. Kirk et al. (2004) found that rotary atomizers at 46.8 L/ha (5 gpa) with smaller droplet sprays (240 µm) resulted it maximum deposition on wheat heads and mylar collectors. A follow-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 (2, 5, and 10 gpa) and droplet sizes of 175 and 350 µm (Fritz et al., 2005). The results showed highest deposition amounts at the lowest spray rates with larger droplet sprays (Fritz et al., 2005).

It is important to consider the ultimate target when selecting application equipment set-ups to maximize deposition. This study was conducted to assess and characterize spray deposition on wheat heads with different combinations of spray rates and droplet sizes and application technologies under field conditions in an effort to optimize aerial application techniques.

Materials and Methods

Based on experience with aerial application and previous wheat deposition related aerial application research, methods were selected that potentially offer improved spray deposition on wheat heads. These methodologies were evaluated on a wheat field near College Station, Texas. Six application treatments, arranged in a randomized complete block with three replications, were examined. Hydraulic nozzles and rotary atomizer treatments were chosen based on setups from previous efforts (Kirk et al., 2004 and Fritz et al., 2005) that resulted in maximum deposition. For the conventional hydraulic nozzle treatments, CP-03 nozzles were selected (CP Products Company, Inc., Tempe, Arizona). The rotary atomizers were ASC-A10H Atomizers (Curtis Dyna-Fog Ltd., Westfield, Indiana). The electrostatic nozzles were solid-body nozzles from Spectrum Electrostatic Sprayers, Inc (Houston, Texas). The treatments and their respective spray rates, $D_{V0.5}$, and droplet size classification (DSC) are shown in Table 1. The volume median diameter, $D_{V0.5,}$ is the diameter of droplet such that 50% of the total volume of droplets is in droplets of smaller diameter. The $D_{V0.5}$ for each treatment was determined using the Aerial Applicators Spray Nozzle Handbook (USDA-ARS AH-726) and the nozzle and aircraft operating parameters. The treatments were applied with an Air Tractor AT-402B (Air Tractor, Inc., Olney, Texas).

Table 1. Application treatment operation parameters and settings.

Trt	Nozzle	*Notation	Deflector Angle	Orifice mm (in.)	Spray Pressure kPa (psi)	Airspeed km/h (mph)	Spray Rate L/ha (gpa)	$D_{V0.5}$ µm	†DSC
1	ASC Rotary Atomizers	RA	--	3.2 (.125)	276 (40)	209 (130)	18.7 (2)	175	VF
2	Spectrum Electrostatics	ES	--	3.2 (.125)	276 (40)	209 (130)	9.4 (1)	150	VF
3	CP-03	LVF	90°	2 (.078)	276 (40)	233 (145)	18.7 (2)	175	VF
4	CP-03	HVF	90°	3.2 (.125)	276 (40)	241 (150)	46.8 (5)	175	VF
5	CP-03	LMD	55°	2 (.078)	276 (40)	160 (100)	18.7 (2)	350	M
6	CP-03	HMD	30°	3.2 (.125)	276 (40)	177 (110)	46.8 (5)	350	M

* The notation column denotes the 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 (5gpa); and L-low, 19 L/ha (2 gpa)) and the second two letters refers to the droplet size spectrum (VF-very fine; and MD-medium). ASC – Rotary Atomizers. ES – Electrostatics.
† Defined by ASAE S572 AUG99 Droplet Spectra Classification; VF – VERY FINE and M – MEDIUM

At each field location, treatments were arranged within the location as a randomized complete block design with three replications, resulting in 3 blocks each with 6 plots each corresponding to a different treatment. For each treatment plot, 5 swaths were sprayed. All treatment swath widths were 20 m (65 ft) with the exception of rotary atomizer treatments which were 15 m (50 ft). Plot lengths were 380 m (1247 ft). The total area sprayed for each treatment plot replicate was 3.8 ha (9.4), except for rotary atomizer treated plots which were 2.8 ha (6.9).

Spray performance variables were documented based on ASAE Standards S327.2 FEB01 and S572 AUG99. These standards define $D_{V0.5}$, Droplet Spectra Classification (DSC), and other pertinent spray parameters. Water-based spray mixtures with surfactant, Triton X-100 (0.25% v/v) and equal per-hectare rates of the fluorescent tracer, Caracid Brilliant Flavine FFN (25 g/ha) (Carolina Color and Chemical Company, Charlotte, NC). Weather parameters were monitored and recorded during all spray applications with a Gill 27005 Anemometer (R. M. Young Company, Traverse City, Michigan), Young 43372VC Relative Humidity and Temperature Probe (R. M. Young Company, Traverse City, Michigan), and a Campbell 21-X data logger (Campbell Scientific, Inc., Logan City, Utah). Weather conditions varied some between each treatment but remained relatively constant during each treatment application (Table 2).

Table 2. Weather conditions for the three field studies averaged over entire treatment application (all three replications spray sequentially).

Treatment	Wind Velocity m/s (mph)	Temperature, °C (°F)	Relative Humidity, %
1	0.5 (1.1)	20.2 (68)	55.6
2	3.9 (8.7)	27.7 (82)	29.3
3	3.0 (6.7)	23.9 (75)	40.5
4	3.8 (8.5)	25.2 (77)	38.3
5	4.1 (9.2)	25.9 (79)	34.2
6	3.7 (8.3)	26.8 (80)	32.0

Meteorological data for each treatment corresponds to approximately 15 minutes (time required to spray the three replications)

Data Collection, Processing and Analysis

To avoid cross contamination between plots, sampling was done only in the center swath for each plot (i.e. swath # 3). Two sampling sites (A & B) (Figure 1) were located 50 m (164 ft) from each edge of each treatment plot. Artificial samplers were placed at each sampling site in five equally spaced sub-stations across the swath immediately prior to spray application. Artificial samplers at each sub-station consisted of a mylar plate (100 cm^2) and a water sensitive paper (WSP) (26 x 76 mm). At each sub- station, one mylar plate and one WSP was oriented horizontally at the top of the crop canopy.

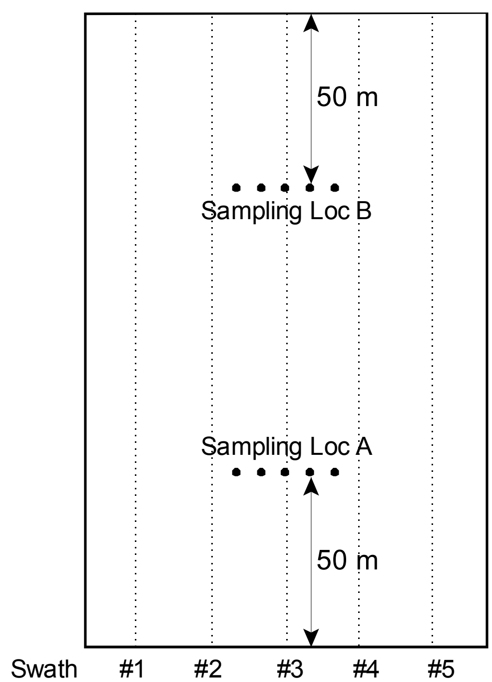

Figure 1. Layout of sampling locations within three different wheat fields.

Immediately after spray application mylar, WSPs and collected wheat heads were placed in labeled plastic bags. Wheat head samples, comprised of ten randomly chosen heads, were collected at each of the five sub-stations at locations A and B. Mylar samples as each sub-station were collected and bagged individually. For each plot, there were ten mylar samples (five from each site A and B), ten wheat head samples (five from each site A and B), and ten horizontal WSP samples (five from each site A and B). All samples were labeled with treatment, replication, sample, and sub-sample information. Samples were placed into insulated coolers immediately after collection for transport to the laboratory for analysis. An additional ten, 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 and 40 ml of ethanol, respectively, in the collection bags. The bags were agitated, and 6 ml of the effluent was poured into a cuvette. The cuvettes were then placed into 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 $\mu g/cm^2$ using a projected area of the sampling media (100 cm^2 for the mylar cards and the measured projected area for the wheat heads). The readings were corrected using tank samples from the actual spray in each test. The minimum detection level for the dye and sampling technique was 0.00007 $\mu g/cm^2$. Following washing, the projected areas of the wheat head samples were determined with a LI-3100 Area Meter (LI-COR, Inc., Lincoln, Nebraska). 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, Texas) 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 spread factor (drop diameter = 0.54*stain diameter – 8.5×10^{-5}*stain diameter).

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

Analysis of deposition data on wheat heads and mylar plates was completed in SAS using PROC MIXED. For each set of sampler specific data, analysis of variation in dye deposition was completed with treatment as a fixed effect. Random effects included replication within location, replication, replication by droplet size by spray rate interaction, sample site within replication, and sub-sample within sample location and replication. The blocks within field were not treated as blocks but as replications, as there were no expected sources of variation within each field location that would contribute to variation in the deposition data.

Results

Deposition on Water Sensitive Paper

The major purpose of the WSP samples was assessment of droplet size for each treatment. Droplet sizing results indicates that target conditions were well met (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 µm 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 µm to 205 µm. On average the 350 µm treatments were 64% of the targeted size.

Table 3. Aerial spray deposit VMD for Water Sensitive Paper samples.

Treatment	VMD (µm)	Standard Deviation of VMD (µm)
RA	150	32
ES	140	42
LVF	136	23
HVF	141	22
LMD	205	67
HMD	239	79

Deposits on Wheat Heads and Mylar Samplers

There was a significant treatment effect (P=0.0001) on deposition of dye on wheat heads. Application treatment LMD resulted in the highest deposition on wheat heads (Table 4). Application treatments ES, LVF, and HVF resulted in the next highest deposition amounts on the wheat heads. Application treatments HMD and RA resulted in the minimum deposition values.

There was also a significant treatment effect (P<0.0001) on deposition of dye on the mylar collectors (Table 4). Application treatments LMD and HMD resulted in the highest deposition on mylar samplers. Applications treatments HVF, RA, and ES resulted in minimum deposition amounts on the mylar cards.

Table 4. 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 HVF HMD RA
Mylar	P < 0.0001	LMD HMD LVF HVF RA ES

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 behavior resulting from each treatment. Figures 2 through 7 are images obtained from collected wheat heads for all six treatments. The figures show the front (A) and back (B) of two randomly selected wheat heads from each treatment.

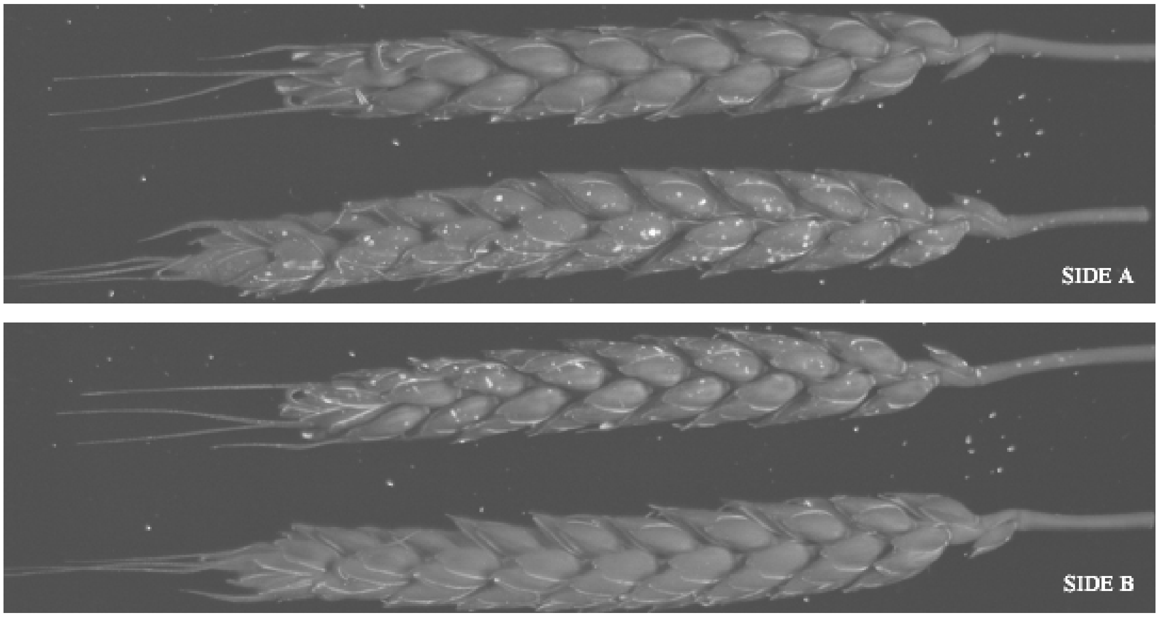

Figure 2. Fluorescent photos obtained from both faces of collected wheat heads obtained from plots treated with Rotary Atomizers (Treatment RA). Top two images are side A and bottom 2 images are side B of same wheat heads rotated 180°.

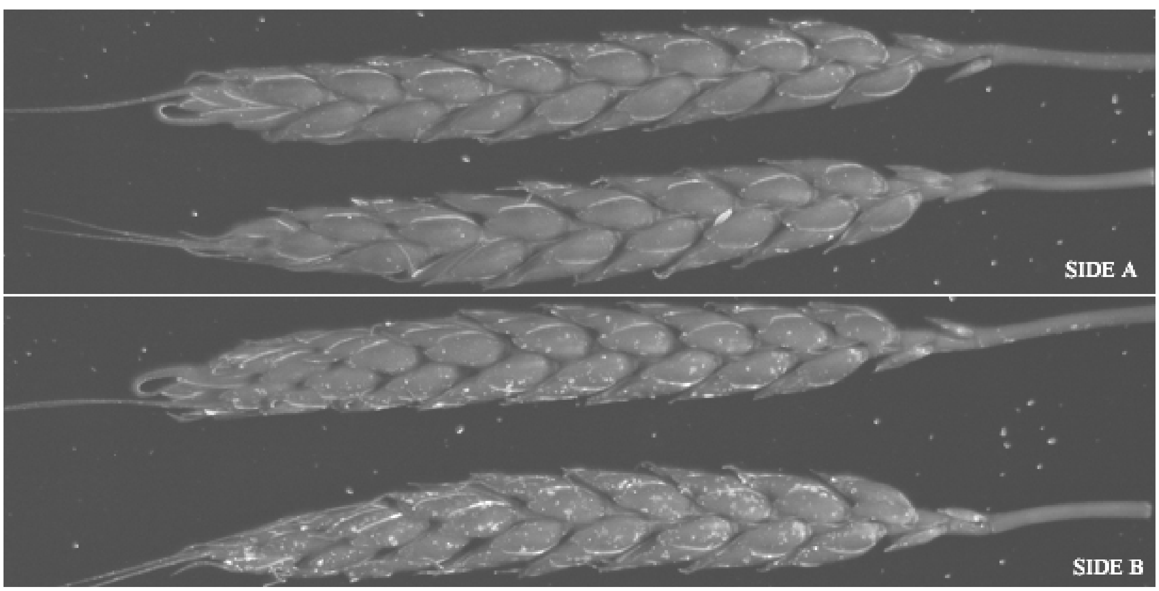

Figure 3. Fluorescent photos obtained from both faces of collected wheat heads obtained from plots treated with Electrostatics (Treatment ES). Top two images are side A and bottom 2 images are side B of same wheat heads rotated 180°.

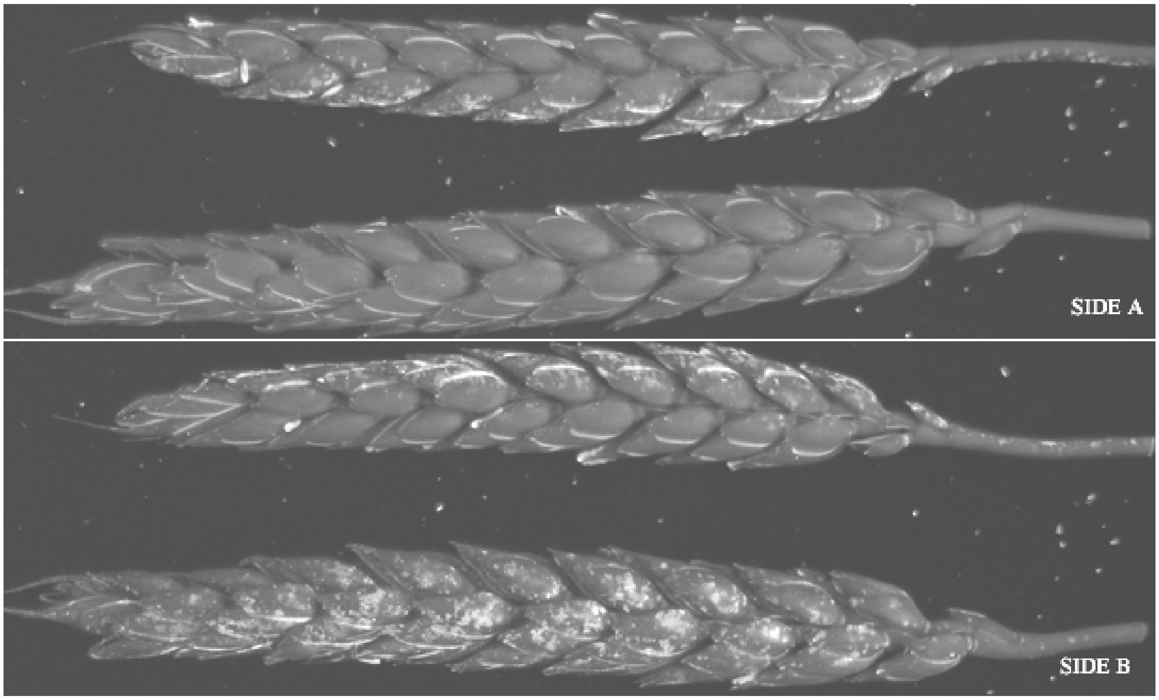

Figure 4. Fluorescent photos obtained from both faces of collected wheat heads obtained from plots treated with CP-03 nozzles (Treatment LVF – Spray Rate of 18.7 L/ha (2 gpa) and $D_{V0.5}$ of 175 µm). Top two images are side A and bottom 2 images are side B of same wheat heads rotated 180°.

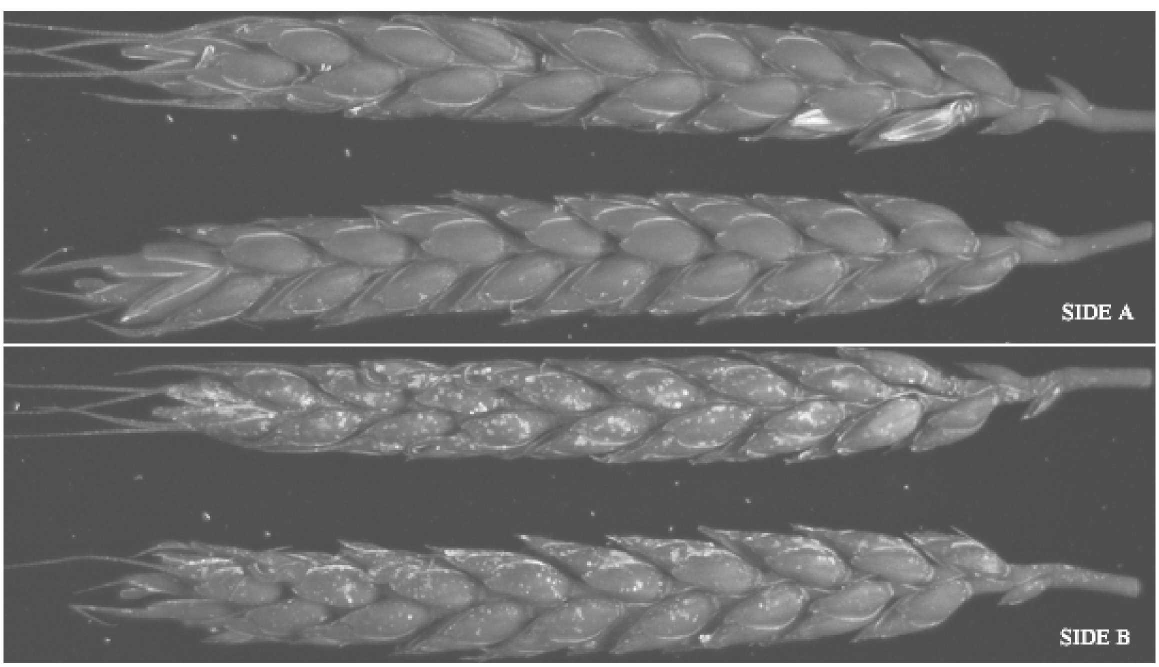

Figure 5. Fluorescent photos obtained from both faces of collected wheat heads obtained from plots treated with CP-03 nozzles (Treatment HVF – Spray Rate of 46.8 L/ha (5 gpa) and $D_{V0.5}$ of 175 µm). Top two images are side A and bottom 2 images are side B of same wheat heads rotated 180°.

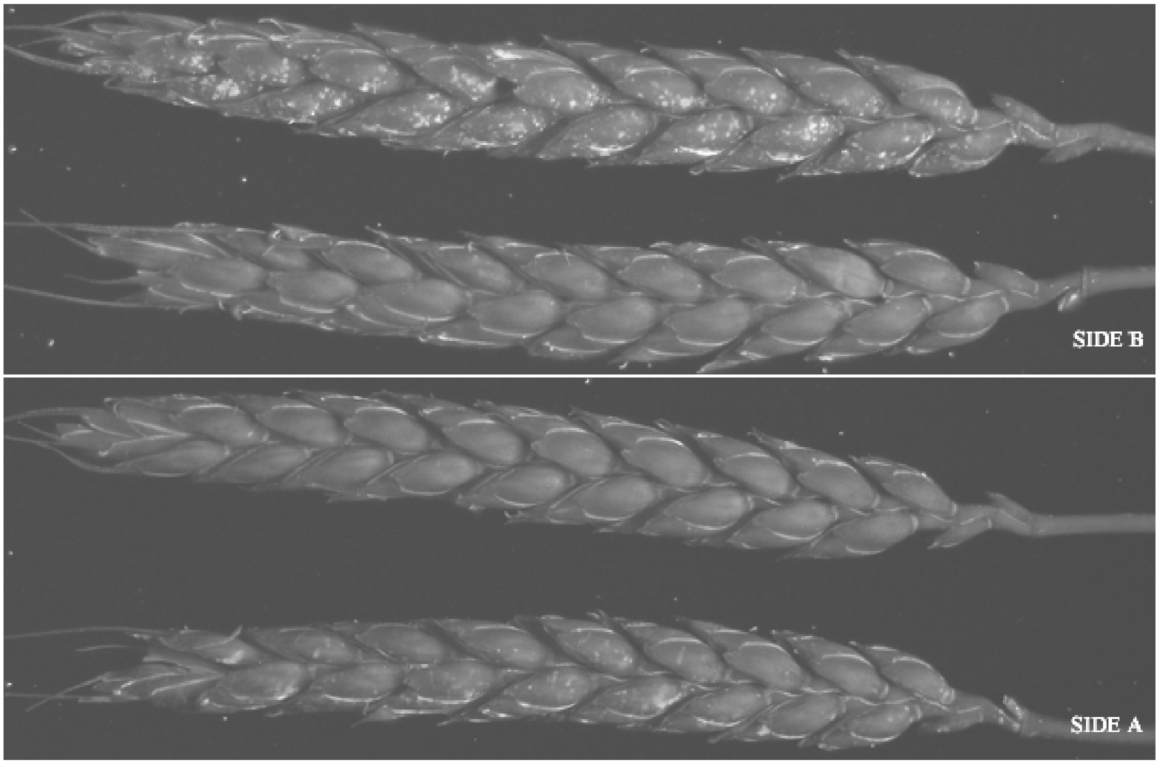

Figure 6. Fluorescent photos obtained from both faces of collected wheat heads obtained from plots treated with CP-03 nozzles (Treatment LMD – Spray Rate of 18.7 L/ha (2 gpa)and $D_{V0.5}$ of 350 µm). Top two images are side A and bottom 2 images are side B of same wheat heads rotated 180°.

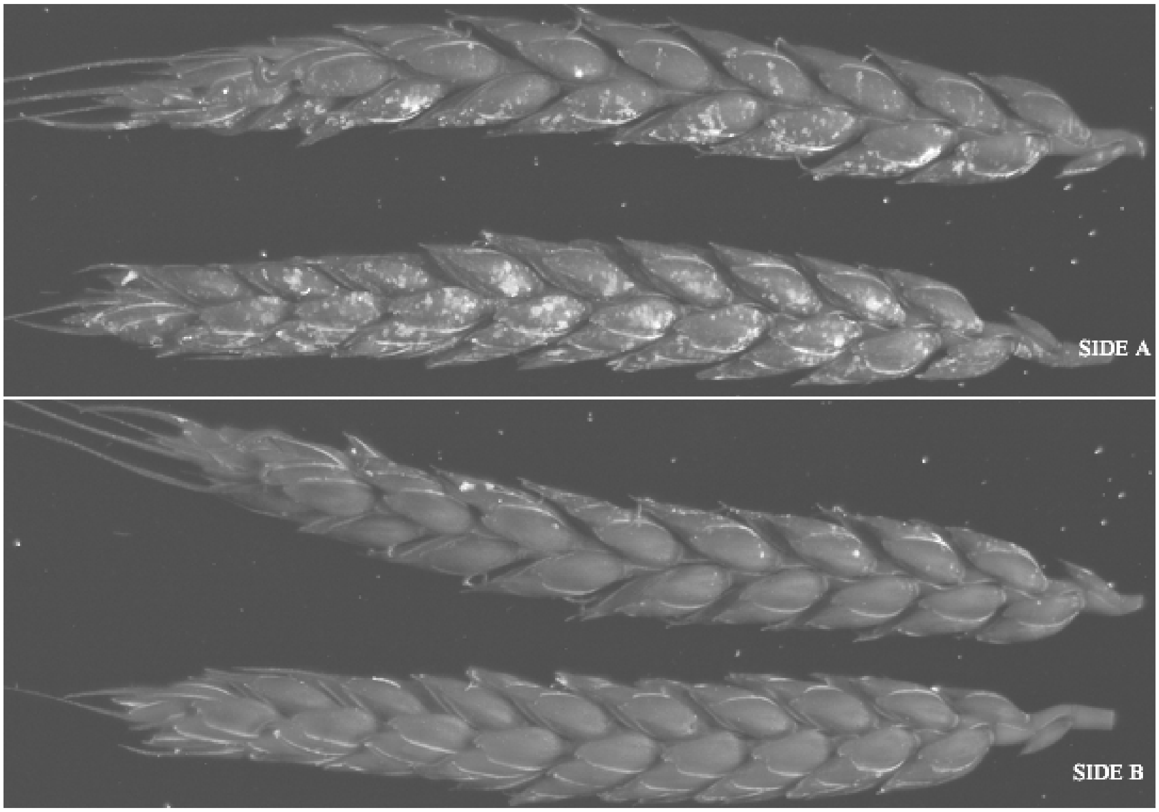

Figure 7. Fluorescent photos obtained from both faces of collected wheat heads obtained from plots treated with CP-03 nozzles (Treatment HMD – Spray Rate of 46.8 L/ha (HMD) and $D_{V0.5}$ of 350 μm). Top two images are face A and bottom 2 images are face B of same wheat heads rotated 180°.

The most interesting result from the wheat heads photographs are the deposition characteristics for each treatment. 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). Equal or greater coverage amounts resulting from different treatments do not indicate that the amount of active ingredient on the wheat heads from different treatments is also in equal or greater amounts. Notice how application from the LMD treatment (Figure 6) has visibly less coverage than application from HMD treatment (Figure 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 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 (Figure 3), did result in near maximum dye deposition amounts on the wheat heads (Table 4). This type of information is very beneficial if a dose response is known for a particular component.

Conclusions

This study evaluated several aerial application technologies to optimize deposition on wheat heads. Both conventional hydraulic technologies as well as electrostatic and rotary atomizer technologies were examined. Overall, hydraulic nozzles applied at a18.7 L/ha (2 gpa) spray rate and $D_{V0.5}$ of 350 µm resulted in maximum deposition on wheat heads. This result directly corresponds to that found in previous similar work (Fritz et al., 2005). Electrostatics resulted in second best deposition amounts on the wheat heads. Higher volume applications resulted in near minimum deposition on wheat heads along with rotary atomizer applications. Previous research (Fritz et al., 2005) in North Dakota and Minnesota under very different meteorological and field conditions also showed that higher application rates had the least deposition on wheat heads. The major benefit of the lower spray rate treatments, especially the electrostatics, for applicators is reduced loading and ferrying time which increases productivity. Additionally, the optimal treatment setup of the hydraulic nozzles at 18.7 L/ha (2 gpa) with a $D_{V0.5}$ 350 µm has a lesser drift potential than the smaller droplet treatments while maximizing deposition of active ingredient on the spray target.

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