VALIDATION OF VARIABLE RATE SPRAY DECISION RULES IN INTRICATE MICRO-METROLOGICAL CONDITIONS

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ABSTRACT

This study evaluated validity of modified spray decision rules formed to operate axial fan airblast sprayer retrofitted for use in citrus production. The sprayer was field tested in a spraying scenario that involved varied crosswind conditions on small (~ 2 m tall and < 1.5 m wide) and medium (~ 3 m tall and < 2.5 m wide) sized citrus canopies. Crosswinds of 1.3, 2.7, and 4.0 m/s, to the sprayer travel path, were generated using the stationary conical air shaker as the air blower unit. To counter the crosswinds, the amount of air-assist to spray mix was increased and resulting spray coverage along with density of droplets deposited at various locations within both canopy types was evaluated. Water sensitive papers (WSPs) were used as deposit targets and an image processing algorithm developed by Chaim et al. (2002) was used to analyze the WSPs.

Modified variable rate spray decision rules that increased 70-80-100% air-assist for medium sized 2-m tall canopy and 80-90-100% for dense 3-m tall canopy at respective increased crosswind of 1.3, 2.3, and 4.0 m/s were effective in compensating the effect of crosswind. For both types of canopies, spray coverage was higher on canopy front and was decreased as the crosswind counter interaction with spray mix increased. Due to coalescing, larger droplets ($D_{v,0.5}$ [volume mean diameter] ~ 1500-2100 µm) were formed on canopy front, whereas coalescing reduced as the droplets penetrated inside the canopy with $D_{v,0.5}$ ranged between ~ 600-900 µm on canopy middle and ~ 400 µm on canopy back targets.

Keywords: Airblast sprayer retrofit, Adjustable air-assist, Spray coverage, Citrus production

INTRODUCTION

Variable rate technology (VRT) in precision horticulture utilizes different sensors and control instrumentation techniques mounted on agricultural vehicles for tree specific spray, fertilizer (granular), or nutrient applications. Application rates can be varied based on different canopy foliage densities or variation of tree sizes within a single row. For example, Gil et al. (2007) used three ultrasonic sensors to detect variable crop width and accordingly varied the nozzle flow rates in real-time using solenoid electro-valves. Alternatively, Pai et al. (2009) measured citrus foliage density using a laser scanner mounted on the front of the airblast sprayer and used this information to control the air-assist to the spray droplets via an automated electro-mechanical air deflector plate. Recently, Pérez-Ruiz et al. (2011) used a geospatial prescription map prepared for Spanish olive trees along with RTK-GPS based sprayer positioning information to control the application rates.

Similarly to above efforts, researchers at the University of Florida, in collaboration with Carnegie Mellon University and Cornell University, have retrofitted an axial-fan airblast sprayer specifically for citrus tree precision spraying that can potentially be able to reduce chemical use, canopy run-off, and ground spraying. It can also increase the targeting accuracy. Retrofitted sprayer can adjust spray output rate, using pulse width modulation controlled solenoid valves. An innovative component of this new system is the use of air-diverting louvers to change the amount of air-assist on the spray mix based on canopy size. The retrofit has been detailed in Khot et al. (2012).

Good agricultural spraying practices require use of sprayers (e.g. conventional axial fan airblast sprayer) in micro-metrological conditions such than wind is steady, not very calm, in the ranges of 1-4 m/s, temperature below 25 °C, and RH greater than 40% (Deveau, 2009). However, in most practical operating conditions these general guidelines would not be available while operating VRT based airblast sprayer in varied sizes citrus canopies, especially in orchards of varied stages and orchards with resets (Fig. 1). Also, the spray application decision rules decided using spray patterns etc. needs to be revised considering instantaneous micro-metrology, i.e., wind speed and direction. Therefore, key objective of this study was to evaluate effect of crosswinds on retrofitted axial fan airblast sprayer performance in terms of spray coverage and deposition on varied size citrus canopies with revised decision rules designed to operate the sprayer in variable rate mode. Also, instead of using traditional fluorometry or colorimetry approaches, this study investigates usefulness of water sensitive paper targets along with image processing approach for spray deposit quantification.

Figure 1 a) two year young sparse, and b) 8-10 year old hedged citrus canopies.

MATERIALS AND METHODS

Experiments were conducted in Citrus Research and Education Center (CREC), University of Florida, managed orchards at Lake Alfred, FL (Lat: 28.1037, Long: 81.7070). The retrofitted sprayer was tested for spray efficacy in a spraying scenario that involved small (about 2 m tall and < 1.5 m wide) and medium (about 3 m tall and < 2.5 m wide) sized citrus canopies.

An axial-fan airblast sprayer (Supersprayer 1000, Durand Wayland, GA), retrofitted for precision spray applications in citrus orchards was used in this study. Figure 2 depicts the experimental setup. Conical citrus mechanical harvesting air shaker was used as the “blower” to generate varied wind speeds during the spray treatments. The blower equipment consisted of a circular axial fan (dia. = 137 cm) and “a rotatable air outlet assembly” (Coppock and Donhaiser, 1981). In this study, the blower was stationed about 16 m away from the test tree centerline and was operated without rotating the air outlet such that wind was blown on to the test canopy counteracting the spray material released by the sprayer (Fig. 2). The blower axial-fan rotations were adjusted, about 600, 1000 or 1400 rpm, to have intended winds of 1.3 (3), 2.7 (6), and 4.0 (9) m/s (mph) on the test tree canopy. Sprayer was operated at 4 km/h for all spray treatments. Water was used as spray liquid and deposits were collected after single pray pass.

Spray treatments involved testing the VRT sprayer decision rules on 2-m and 3-m tall canopies. Formulated rules were to: a) use nozzles 2-4 at 100% flow rate and with 70% air-assist for up to 2-m tall, medium/dense canopies, and b) use nozzles 2-6 at 100% flow rate and with 80% air-assist for up to 3-m tall, medium/dense canopies. Above two decision rules, decided based on spray pattern tests (data not shown), were assumed to be valid only for up to 1.3 m/s (i.e., 3 mph) wind speed. Therefore, decision rules were modified for increased cross-winds, i.e., increased air-assist to the spray mix for increased crosswind. For up to 2.7 m/s (6 mph) wind speed, the air-assist was increased to 80% and 90% for 2-m and 3-m tall canopies, respectively. Any increase in crosswind up to 4.0 m/s (9 mph), needed 100% air-assist to the spray liquid in both types of canopies considered. The treatments of 1.3, 2.7, and 4.0 m/s are henceforth written as ‘Low’, ‘Med’, and ‘High’ wind treatments, respectively.

Water sensitive papers (WSPs) (size: 26 × 76 mm) from TeeJet® Technologies (Spraying systems co. Wheaton, IL) were used as artificial targets. Tree canopy was divided into two sections (A & B). For 2-m tall canopies, in the first section (A), deposits were placed at three vertical heights of 0.6, 1.2, and 1.8 m on the canopy (Fig 2. inset- front view) and at three lateral locations, i.e., canopy front, canopy middle, and canopy back (Fig 2. inset- top view). This sequence was repeated for remaining half of the tree (section-B). Additionally, to evaluate spray drift, deposits were placed on wooden blocks placed on ground in adjacent row middles from the test tree at 0, 3, 10, 16 m downwind. Thus, each treatment run involved 22 deposits. In case of 3-m tall canopies, the above procedure was repeated with additional sampling at 2.5 m, i.e., total of 28 deposits per each treatment run.

Experiments involved three wind treatments that were randomized and replicated three times (total of nine runs) per canopy size. Before each spray run, maximum wind speed at each of the spray deposit location on the target canopy were recorded using handheld ultrasonic wind meter (model: Wind Scribe, Davis Instruments, Hayward, CA).

During the applications, wind speed and wind direction at 2-m above ground were recorded. A 2-axis sonic anemometer was used to record wind parameters at a rate of 4 Hz. Table 1 reports these parameters. Other micro-metrological parameters such as air temperature (2 m above ground), soil temperature, and humidity recorded at a nearby Florida Automated Weather Station (FAWN) ranged from 18-30 °C, 23-30 °C, and 37-66%, respectively.

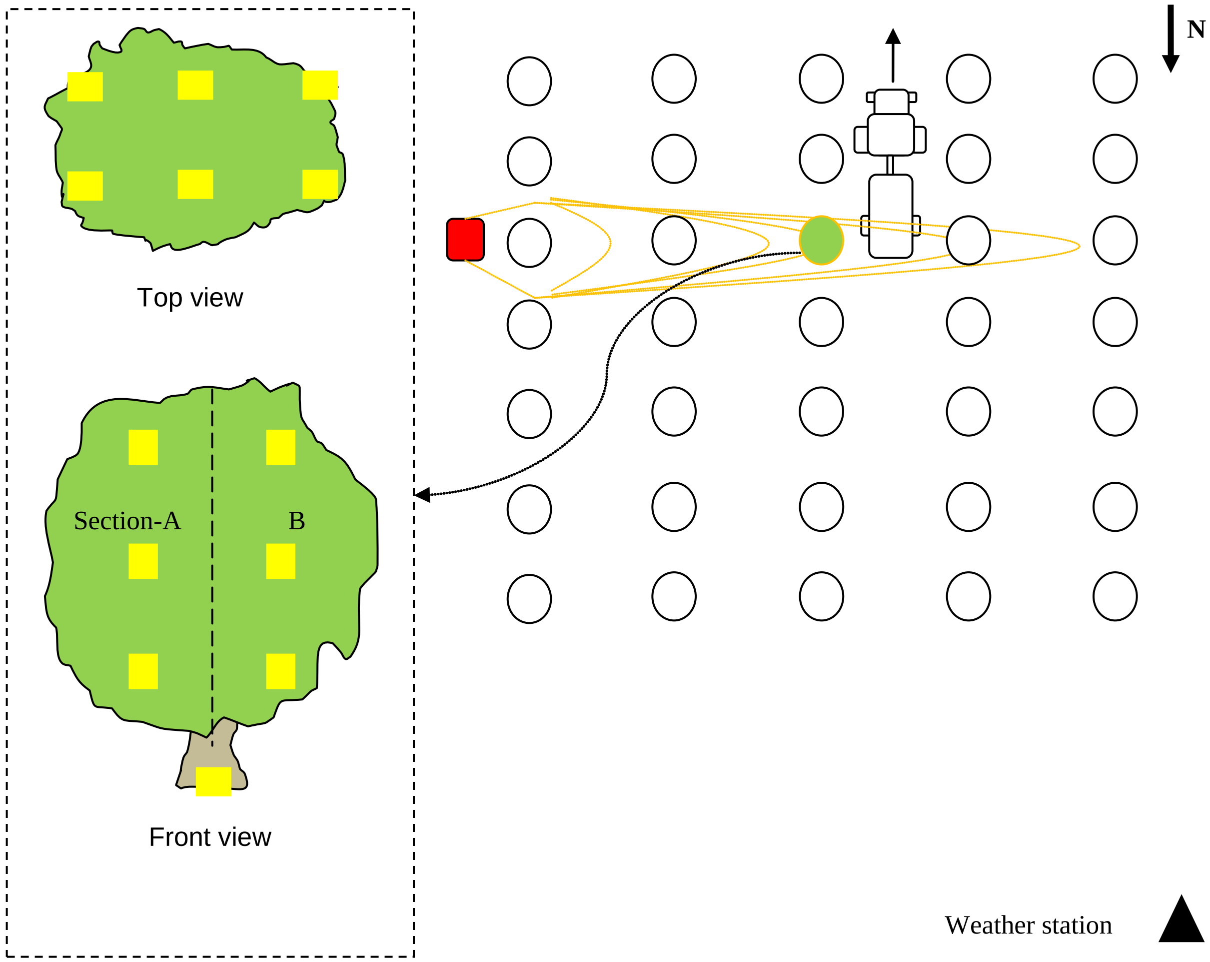


Figure 2. Schematic of the field experiments with inserts of target locations (front and top view of 2-m tall canopies).

After each spray run, each of the WSPs were collected and placed in reselable plastic bags (size: 7.6 × 12.7 cm). Later, each WSP was scanned at 600 dpi resolution and stored as the bitmap image. The images were processed using a computer program developed by Chaim et al. (2002). For each scanned image, the program outputs the number of droplets, volume median diameter (µm), spray density (droplets/cm^2), and coverage (%). These parameters were stored in excel file format for further statistical analysis.

Statistical Analysis Software (SAS$^{®}$) (ver. 9.2, SAS Institute Inc. Cary, NC) was used to perform descriptive as well as ANOVA analysis. Significant effects of various treatment combinations were inferred at the 5% level and the 'LSMEANS' option was used to compare least square mean differences.

Table 1. Meteorology parameters measured during application treatments (at 2-m above ground).

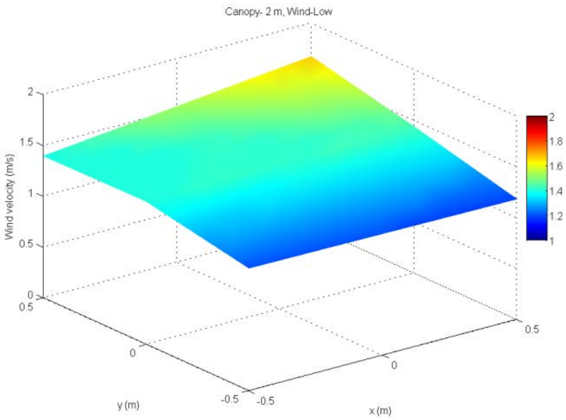
Wind Treatment	Wind Speed (m/s)		Wind Direction (˚ from N)	
	Range	Mean ± SD	Range	Mean ± SD
Tree height- 2 m				
Low	0-7	1.7 ± 0.8	3-356	140 ± 31
Med	0-5	1.9 ± 0.8	39-345	152 ± 35
High	0-5	1.8 ± 0.8	1-319	149 ± 30
Tree height- 3 m				
Low	0-5	1.5 ± 0.8	0-359	220 ± 91
Med	0-5	1.7 ± 0.8	0-359	240 ± 65
High	0-5	1.5 ± 0.7	0-359	206 ± 49

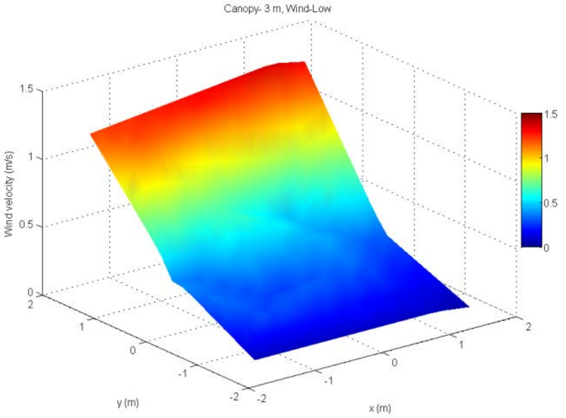
RESULTS AND DISCUSSION

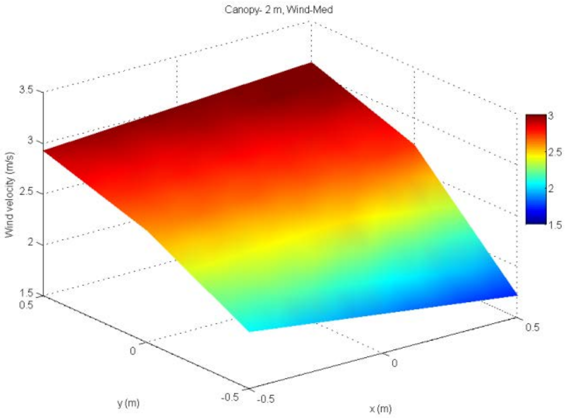
Figure 3 depicts the sheet of the crosswind, to sprayer travel path (x-direction), on the canopies (y-direction represent canopy width perpendicular to sprayer travel and {x, y = (0, 0) represent tree trunk}). Evidently, wind entering the canopy was at higher speed than the wind crossing through canopy. This was apparent for dense canopies (3-m tall), where not much of the wind penetrated through canopy (< 1 m/s). As reported in methods section, during each run, the spray was applied on the test canopy such that the wind from blower countered spray penetration across the canopy.

Figure 4 shows the typical WSPs after spray run and image analysis based spray coverage results for WSPs located at canopy front, canopy middle and canopy back during one of the spray treatments. Evidently, the imaging processing software developed by Chaim et al. (2002) was useful to analyze the WSPs scanned at 600 dpi and provided quantifiable results for further analysis. Figure 5 represents the percent coverage, data averaged for various vertical heights, at canopy front, canopy middle, and canopy back. Trends suggest that the increased air-assist to the spray droplets helped reducing the adverse effect of crosswinds (1.3-4.0 m/s) and in maintaining the spray coverage similar to that of spraying during low wind conditions (1.3 m/s).

For 2-m tall canopies, spray coverage on canopy front was comparable for all the crosswind conditions of 1.3, 2.7, and 4.0 m/s. Clearly, spray material covered 50% or more of canopy front whereas the coverage reduced considerable as it reached canopy middle and substantially across the canopy (< 10%). Similar trend was observed for a 3-m tall and dense canopy. Overall, as crosswind did not penetrate through the dense canopy, the spray coverage on canopy front was higher than at canopy middle and canopy back where crosswind was predominantly higher (Fig. 3 right).


Canopy- 2 m, Wind-Low


Canopy- 3 m, Wind-Low


Canopy- 2 m, Wind-Med

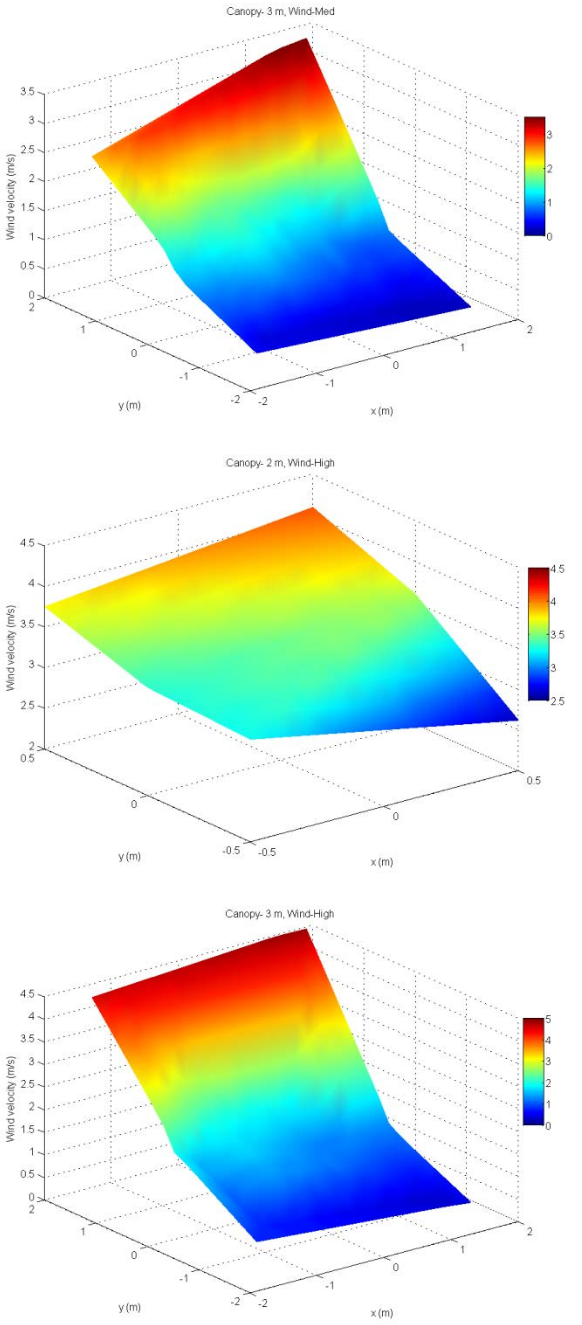


Figure 3. Wind speed measured on test canopies during various wind treatment conditions.

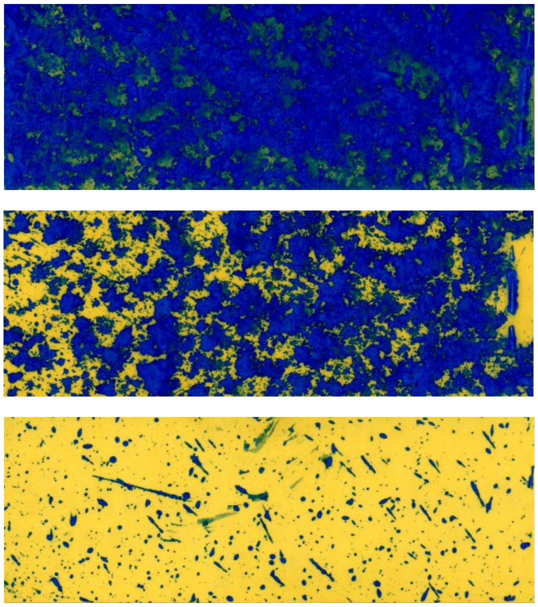


Figure 4. Sample of water sensitive paper targets with spray deposition on two meter tall (a) canopy front, (b) canopy middle, and (c) canopy back during 'high' wind condition spray application.

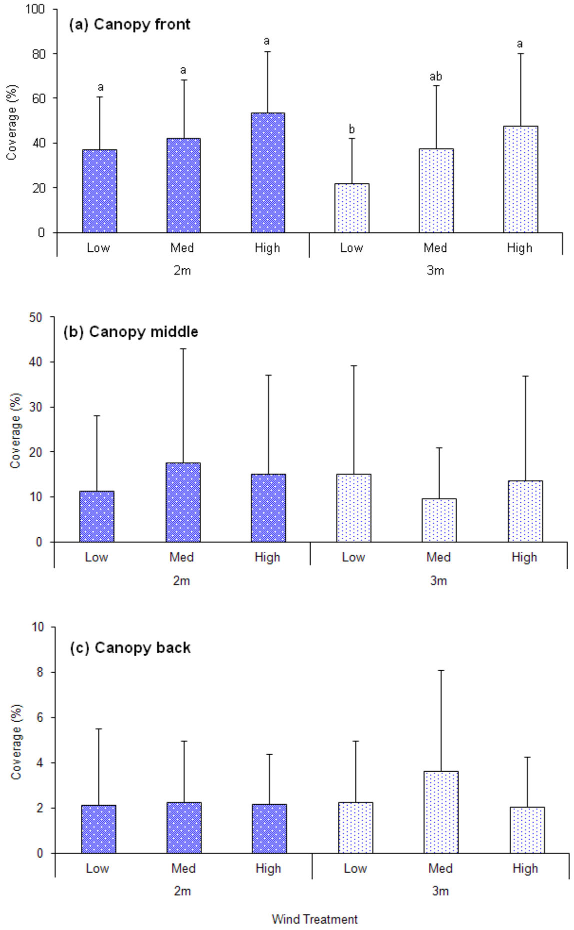


Figure 5. Spray coverage on two and three meter canopy during increased air-assists to counter the crosswind field conditions. Except at canopy front on 3-m tall trees, coverage was not significantly different for low, medium and high wind treatments. Data for each of the tree type was analyzed separately.

Note that weather conditions on both the experiment days were somewhat different. Although the wind speeds were < 2 m/s, wind on the second experiment (on dense and 3-m tall canopy) was from south-west whereas it was from south-east during the experiments on 2-m tall canopies. Thus, addition to canopy density, the change in wind direction might have resulted in increased spray coverage even at higher crosswinds on taller canopy.

Table 2 reports the droplet size and density (per cm^2) on the WSP deposits for both types of canopies front, middle and back. On canopy front, coalescing of multiple spray droplets per unit area resulted in much larger droplet size (as determined by image processing software); whereas for inside and across the canopy, the decreased spray material penetration resulted in much smaller and less overlapping of droplets per unit area. Note that the droplet density also decreased with increased spray material penetration across the canopy. Droplet size remained fairly constant for low and medium crosswind conditions at canopy front, middle and back. However, primarily due to increased wind resistance at higher crosswind, more of spray material might have been deposited on canopy front than insider and across the canopy and hence would have increased the droplet density and size.

Table 2. Spray droplet size and deposition density on deposits at studied canopies front, middle and back.

Wind Treatment	2-m Tall Canopy			3-m Tall Canopy		
	Density (droplets/cm^2)			Density (droplets/cm^2)		
	Mean	Std. Dev.	$D_{v,0.5}$ (μm)	Mean	Std. Dev.	$D_{v,0.5}$ (μm)
Canopy front						
Low	91	93	1754	273	334	1207
Med	96	55	1747	156	184	1515
High	110	82	2143	128	123	1834
Canopy middle						
Low	31	37	780	69	97	734
Med	58	52	979	89	75	584
High	94	71	890	103	75	721
Canopy back						
Low	22	36	419	33	36	357
Med	34	32	417	52	40	380
High	63	50	416	47	37	447

$D_{v,0.5}$ = volume median diameter of droplets deposited on WSP.

CONCLUSIONS

Modified variable rate spray decision rules that increased 70-80-100% air-assist for medium sized 2-m tall canopy and 80-90-100% for dense 3-m tall canopy at respective increased crosswind of 1.3, 2.3, and 4.0 m/s were effective in compensating the effect of crosswind. Water sensitive papers as spray deposits, along with image processing approach, were able to reduce the time and labor required for laboratory analysis based spray quantification and was effective in quantifying not only the percent spray coverage but also the droplet size at various locations of studied canopies. For both types of canopies, spray coverage was higher on canopy front and was decreased as the crosswinds counter interaction with spray mix increased. Also, due to coalescing, larger droplets ($D_{v,0.5}$ ~ 1200-2100 µm) were formed on canopy front whereas coalescing reduced as the droplets penetrated inside the canopy with $D_{v,0.5}$ ranged between ~ 600-1000 µm on canopy middle and ~ 400 µm on canopy back WSP deposits.

Acknowledgements Authors would like to thank USDA-SCRI for their funding and support for this research. We would also like to extend our special thanks to Mr. Francisco Garcia-Ruiz, Dr. Asish Mishra and Mr. Tony McIntosh for their assistance during the study.

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