Evaluation of Low-volume Sprayers Used in Asian Citrus Psyllid Control Applications

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SUMMARY. The asian citrus psyllid [*Diaphorina citri* (Sternorrhyncha: Psyllidae)] is a detrimental pest to citrus (*Citrus* spp.) crops when it serves as a vector of the pathogen that causes greening (huanglongbing). Transmission of this disease causes mottling, chlorosis, dieback, and reductions in fruit size and quality. Citrus producers have found that many pesticides, when applied properly, are very effective at suppressing or eliminating asian citrus psyllids in groves. Due to the threat of greening, several pesticides have been granted Special Local Needs registration for use in the state of Florida if the product is sprayed with a volume median diameter of 90 μm or greater. A number of studies involving numerous citrus sprayers and a.i. were conducted to determine the droplet sizes generated by different sprayers operating under user-established settings and the adjustments required to those settings for the sprayers to meet the 90-μm requirement. In the sprayer tests, it was found that reductions in engine speed or increases in flow rate were required to increase droplet sizes to meet the product label-required droplet size. As the equipment tested here represent the most typical application equipment used in Florida for asian citrus psyllid control, these results will provide applicators, growers, and extension agents with general guidelines to ensure that spray systems are operated in a manner that complies with label restrictions.

The asian citrus psyllid is a detrimental pest to citrus crops when it serves as a vector of the pathogen that causes greening [huanglongbing (HLB)]. Transmission of this disease causes mottling, chlorosis, dieback, and reductions in fruit size and quality (Halbert and Manjunath, 2004). Once a tree is infected, there is no cure, and trees may only live for another 5 to 8 years, potentially never bearing usable fruit. It is well established that the presence of asian citrus psyllids and the vectored pathogen necessitate chemical control in the form of pesticide applications (Tolley, 1990). Given the seriousness of the disease, it is important to protect even apparently disease-free trees (Aubert, 1990), especially with new growth flush (Aubert 1987). Recommended treatment intervals range from 10 to 13 treatments per year (Roistacher, 1996) to every 7 to 20 d (Gonzales and Viñas, 1981), with area-wide treatments being preferred (Aubert 1990). Supriyanto and Whittle (1991) recommend high-efficacy pesticides as essential to provide sufficient control to significantly delay a greening epidemic. It can be further conjectured that optimal application techniques also are critical to obtaining maximum biological control of asian citrus psyllids.

Stover et al. (2002), in a survey to indentify current spray application practices on citrus crops in Florida, identified three predominate sprayer types, including two airblast sprayers at mid- and high-volume application rates and a low-volume application rate air-assisted sprayer, with spray rates ranging from 25 to 750 gal/acre. Sprayer type is generally selected by the operator based on experience and/or perceived coverage and deposition of spray material within the citrus canopy. The selected sprayers can typically be modified to generate spray plumes that fit tree contours through changes in nozzle numbers, and orientation of and/or oscillation of airflow (Stover et al., 2003). With the need for numerous spray treatments for asian citrus psyllid control, applicators are looking to and adapting for use a number of spray application machines initially targeted for the mosquito vector control industry. Machines that apply agrochemical products at these low-volume rates allow applicators to respond to the need to treat large numbers of acres repeatedly in a timely manner. These machines can produce droplets with volume median diameters that range from 5 to 210 μm, depending on spray solution and equipment setup (Hoffmann et al., 2007a).

The list of pesticides approved for application to control asian citrus psyllids in Florida is limited. As a result of the urgent need for control, applicators in Florida have been granted Special Local Needs provisions on a number of insecticides, including spinetoram (Delegate® WG; Dow

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
9.3540	gal/acre	$L\cdot ha^{-1}$	0.1069
2.54	inch(es)	cm	0.3937
1	micron	μm	1
0.4470	mph	$m\cdot s^{-1}$	2.2369
70.0532	oz/acre	$g\cdot ha^{-1}$	0.0143
6.8948	psi	kPa	0.1450

AgroSciences, Indianapolis), diflubenzuron (Micromite® 80WGS; Chemtura, Middlebury, CT), fenpropathrin (Danitol 2.4 EC; Valent, Walnut Creek, CA), and zeta-cypermethrin (Mustang; FMC, Philadelphia). All of these Special Local Needs labels require air-blast or air-assisted sprayers with application rates of no less than 2 gal/acre and with volume median droplet diameters of 90 μm or larger. Most labels allow the addition of adjuvants or other tank-mix partners as long as the other restrictions are maintained; however, fenpropathrin does not allow use of additional adjuvants. No information is given regarding the reasoning behind the 90-μm lower limit, though it is likely based on risk assessment analysis for spray drift. The Special Local Needs labels also do not specify an upper limit on the droplet size. Given that spray droplet size is dependent on and changes with varying combinations of spray equipment, equipment setup, and spray product (Hoffmann et al., 2007b), the objectives of this work were: 1) evaluate three sprayers, under laboratory conditions, for droplet size produced from a.i. formulations and the necessary equipment adjustments needed to meet the Special Local Needs label; 2) conduct "on-site" evaluations of production application equipment for droplet size when operating under normal conditions; 3) adjust the individual sprayer's operating parameters to produce a volume median diameter of 90 μm or greater to ensure compliance with the Special Local Needs labels; and 4) document the general operational modifications required for machine type to provide guidance for future spray calibrations.

Materials and methods

Sprayer droplet size testing was completed in two stages: one looking at three sprayers and five a.i. under laboratory conditions and the second, a field-based evaluation of production sprayers brought to a central location by local applicators. The first laboratory-based work was conducted at the U.S. Department of Agriculture-Agricultural Research Service (USDA-ARS) Areawide Pest Management Research Unit's Riverside campus facilities in College Station, TX. The three sprayers to be evaluated were provided by the equipment manufacturers. The field-based evaluations were conducted at two locations in central Florida. Both sets of trials followed the same testing protocols with the exception of the field-based trials not using a.i. formulations. These procedures, along with greater details on the site-specific testing, are discussed further in the following sections.

General testing procedures. To evaluate the droplet size produced by a particular sprayer and spray formulation combination, the sprayer was first operated under its normal factory or user-established settings. Basically, the sprayer was initially operated as-is. A droplet measurement system (Sympatec, Clausthal, Germany) mounted on a custom-made forklift mount was used to measure droplet size at the sprayer nozzle outlet. The unit was positioned such that the location of measurement was ≈1 to 2 m from the outlet of the sprayer (Fig. 1). This distance varied somewhat from sprayer to sprayer depending on the droplet density of the resulting spray cloud and the width of the spray plume. Wider spray plumes required a closer distance to avoid depositing spray material on the lenses of the droplet measurement unit. Denser sprays required further distance to insure that the spray cloud density did not prevent the diffracted laser light from reaching the measurement sensor. The spray cloud from the sprayer was directed through the laser beam for 10 to 20 s during which time droplet size measurements of the spray cloud were made. The time that the spray cloud was directed through the optical path of the laser varied between sprayers depending on the width of the spray plume generated by the sprayer. The entire spray plume for each sprayer was measured by traversing the laser through the plume using the forklift (ASTM International, 2009). Three replicated measures were made for each unique piece of equipment and specific set of operational conditions.

Droplet sizing system. The Helos laser diffraction droplet sizing system (Sympatec), which uses a 623-nm helium-neon laser, was fitted with an R5 lens, resulting in a dynamic size range from 0.5 to 875 μm in 32 sizing bins. The authors found that when using the laser system under adverse conditions (outdoors and mounted to a forklift), the last channel (i.e., sizing bins) of the Helos system should be turned off such that it is not factored into the droplet size measurement results. This channel represents the largest droplet size and tends to pick up some "noise" or random signals that typically result from equipment vibration or scattered ambient light. With this channel turned off, the dynamic range of the instrument was from 0.5 to 735 μm. These channels were not turned off if any droplets were measured within two sizing bins of the nearest deactivated channel.

The spray droplet size data were determined and reported as a mean and standard deviation corresponding to the data measured during the three replications for each combination of sprayer and pesticide. Means and standard deviations of the volume median diameter [VMD or $D_{V0.5}$ (ASTM International E1620-97, 2004)], $D_{V0.1}$, and $D_{V0.9}$ were determined. The $D_{V0.5}$ is the droplet diameter in micrometers where 50% of the spray volume is contained in droplets smaller than this value (ASTM

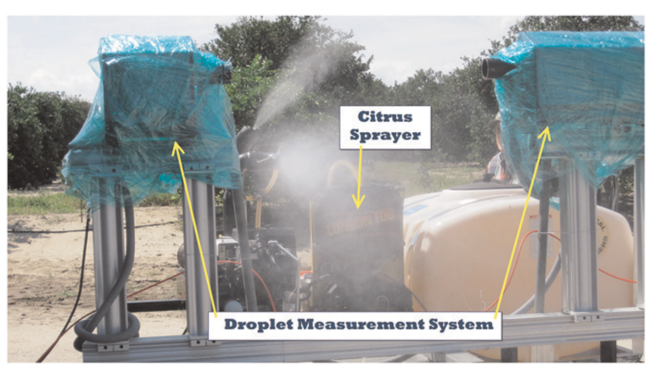

Fig. 1. Testing setup showing the droplet measurement system with the spray plume from the citrus sprayer directed through the laser beam of the droplet measurement system.

Standard E1620, 2004). Similarly, the $D_{V0.1}$ and $D_{V0.9}$ values are the diameters at which 10% and 90%, respectively, of the spray volume is contained in droplets of these sizes.

ACTIVE INGREDIENT TESTS. For the laboratory studies, five a.i. along with water plus a nonionic surfactant (NIS) were used. The use of a specially designed scrubbing system allowed for the use of these a.i. without adverse environmental impacts. Three liquid-based products were used: malathion (Malathion 5EC; Drexel Chemical, Memphis, TN), dimethoate (Dimethoate 4E; Arysta LifeScience North America, Cary, NC), and fenpropathrin. Two of the products were wettable powders: diflubenzuron and spinetoram. The rates at which these products were tested are shown in Table 1. For all a.i. tests, spray rates were maintained at 3 gal/acre. For each of the three sprayers tested, the first step was to run the sprayer at the factory settings using water to determine a benchmark for further modifications. Depending on the measured $D_{V0.5}$, engine speed was modified such that the 90-µm lower size requirement was met. The goal for each a.i. formulation tested was to determine the appropriate engine speed settings that resulted in compliance with the Special Local Needs permit.

CITRUS SPRAYER CALIBRATION RODEOS. The field evaluations were organized by the Florida Extension Service in Lake Placid, FL, and Haines City, FL. Growers and applicators in the region were invited to bring their equipment to these locations for droplet size measurements. Thirty-three machines were evaluated representing 16 different models of sprayers. Water with 0.25% volume/volume addition of a NIS (R-11; Wilbur-Ellis, Walnut Creek, CA) was used during these tests as there were a large number of spray trials conducted and a large number of people involved. This prevented any environmental contamination or adverse health effects. The water plus NIS solution simulates most water-based insecticide sprays well (Hoffmann et al., 2007a, 2007b). Each sprayer tested was initially run at the user settings. Based on the measured $D_{V0.5}$, engine speed and, in a few cases, sprayer pressure were adjusted until the 90-µm size requirement was met. Typically, engine speed was first reduced to its minimum level and if the resulting measured $D_{V0.5}$ was still less than 90 µm, spray pressure was increased.

An example of the data reports that were provided to each of the applicators is shown in the Appendix (Fig. 2).

Table 1. Five a.i. (three liquid and two wettable powders) and the rates at which they were used in the sprayer calibration trials.

Liquid formulation	Application rate (oz/acre a.i.)[z]
Malathion	9.0
Dimethoate	13.9
Fenpropathrin	6.2
Wettable powders	**Application rate (oz/acre a.i.)**
Diflubenzuron	5.0
Spinetoram	1.0

[z]1 oz/acre = 70.0532 $g \cdot ha^{-1}$.

Results

ACTIVE INGREDIENT TESTS WITH THREE SPRAYERS. Final equipment settings required to meet the $D_{V0.5}$ 90-µm size requirement for each a.i. are shown in Tables 2 through 4 for the three sprayers tested. Droplet size at the factory settings for water and water plus NIS are also included for reference. For the London Fog model 18–20 sprayer (London Fog, Long Lake, MN) (Table 2), initial testing with water and water plus NIS with the machine operating at 2810 and 1850 rpm, respectively, and a rate of 1.9 $L \cdot min^{-1}$ produced $D_{V0.5}$ of 57.8 ± 13.2 and 85.9 ± 1.2 µm (mean ± SD of three replications), respectively. Two of the a.i. formulations, diflubenzuron and spinetoram, produced $D_{V0.5}$ values that were at or near the 90-µm requirement while operating the sprayer at 1500 rpm while two, fenpropathrin and malathion, required reducing the engine speed to 1350 rpm. The dimethoate formulation was such that even at the lowest engine speed setting (1350 rpm), the 90-µm size requirement could not be met.

For the Curtec sprayer (Curtec of Florida, Vero Beach, FL), water and water plus NIS resulted in $D_{V0.5}$ that were greater than 90 µm at factory settings. Dimethoate and diflubenzuron formulation also achieve the 90-µm requirement at the factory settings, while the malathion, spinetoram, and fenpropathrin formulation required engine speeds to be reduced to 4800, 4000, and 4000 rpm, respectively.

For the Proptec sprayer (Ledebuhr Industries, Williamston, MI), water and water plus NIS resulted in $D_{V0.5}$ values that met the 90-µm requirement. Spinetoram and diflubenzuron formulations also met the 90-µm requirement at the 5100-rpm factory setting, while malathion and fenpropathrin formulations required the engine speed to be reduced to 3500 rpm.

CITRUS SPRAYER CALIBRATION RODEOS: SINGLE MACHINE EVALUATIONS. During the calibration rodeos, there were 17 unique models of machines evaluated. Fourteen of the models only had one machine of that type that was tested. Two, the Dyna-Fog Ag-Mister LV-8 (Curtis Dyna-Fog, Westfield, IN) and the London Fog model 18–20, had multiple machines of that type tested.

Of the individual machines tested, eight had a $D_{V0.5}$ of 90 um or greater (Table 5). Three of the remaining sprayers were able to be adjusted via spray pressure or engine speed to achieve a $D_{V0.5}$ near or greater than 90 µm. One of the sprayers, MaxCharge ES100 (Electrostatic Spraying Systems, Watkinsville, GA), was designed to generate droplets with a $D_{V0.5}$ of between 30 and 40 µm to optimize the electrostatic charge that it imparts to the spray droplets.

There were 14 Dyna-Fog Ag-Mister LV-8 (LV-8) and six London Fog model 18–20 citrus sprayers evaluated in the calibration rodeos (Table 6). Each row of data presented in Table 6 represents a unique machine. These machines were all of different age, levels of maintenance, degree of user modification, and standard operating settings thus variation in spray droplet size among the machine was expected. Of the 14 LV-8 sprayers, four were version 1 (LV-8-V1), one was version 2 (LV-8-V2), and nine sprayers contained some modifications of pumps and spray lines that made it difficult to distinguish a specific version. Therefore, all data are presented by individual machine, with no attempt to characterize

Table 2. Effects of a.i. and engine speed on spray atomization for the London Fog model 18–20 sprayer (London Fog, Long Lake, MN).

Formulation	Engine speed (rpm)	Rate per atomizer (gal/min)[z]	Droplet size[y]		
			$D_{V0.1}$ y (µm ± SD)	$D_{V0.5}$ (µm ± SD)	$D_{V0.9}$ (µm ± SD)
Water	2810	0.6	22.3 ± 5.1	57.8 ± 13.2	110.6 ± 22.3
Water + 0.25% NIS[x]	1850	0.6	30.2 ± 2.3	85.9 ± 1.2	214.7 ± 14.8
Diflubenzuron	1500	0.6	38.1 ± 0.4	94.0 ± 2.7	305.5 ± 6.5
Spinetoram	1500	0.6	35.1 ± 0.5	86.4 ± 0.6	260.7 ± 12.9
Fenpropathrin	1350	0.6	38.1 ± 0.7	91.4 ± 0.4	322.2 ± 10.5
Malathion	1350	0.6	37.1 ± 1.0	92.0 ± 0.9	279.2 ± 9.9
Dimethoate	1350	0.6	30.0 ± 2.7	79.6 ± 2.8	205.1 ± 52.7

[z]1 gal = 3.7854 L.
[y]$D_{V.01}$, $D_{V.05}$, and $D_{V.09}$ = the droplet diameter where 10%, 50%, and 90%, respectively, of the spray volume is contained in droplets smaller than this value. Values represent the mean of three replications; 1 µm = 1 micron.
[x]NIS = nonionic surfactant (R-11; Wilbur-Ellis, Walnut Creek, CA).

Table 3. Effects of a.i. and engine speed on spray atomization for the Curtec sprayer (Curtec of Florida, Vero Beach, FL).

Formulation	Engine speed (rpm)	Rate per atomizer (gal/min)[z]	Droplet size[y]		
			$D_{V0.1}$ (µm ± SD)	$D_{V0.5}$ (µm ± SD)	$D_{V0.9}$ (µm ± SD)
Water	5100	0.3	41.3 ± 9.4	111.8 ± 12.8	173.6 ± 17.9
Water + 0.25% NIS[x]	5100	0.3	35.3 ± 5.2	94.9 ± 4.6	149.1 ± 4.2
Dimethoate	5100	0.3	37.9 ± 5.9	96.7 ± 11.0	167.3 ± 11.5
Malathion	4800	0.3	31.2 ± 1.3	88.9 ± 0.6	168.7 ± 9.0
Spinetoram	4000	0.3	66.0 ± 23.1	126.4 ± 11.9	200.5 ± 13.1
Diflubenzuron	5100	0.3	39.9 ± 3.7	105.2 ± 6.4	185.5 ± 11.4
Fenpropathrin	4000	0.3	44.3 ± 1.7	113.2 ± 2.9	218.6 ± 33.5

[z]1 gal = 3.7854 L.
[y]$D_{V.01}$, $D_{V.05}$, and $D_{V.09}$ = the droplet diameter where 10%, 50%, and 90%, respectively, of the spray volume is contained in droplets smaller than this value. Values represent the mean of three replications; 1 µm = 1 micron.
[x]NIS = nonionic surfactant (R-11; Wilbur-Ellis, Walnut Creek, CA).

Table 4. Effects of a.i. and engine speed on spray atomization for the Proptec sprayer (Ledebuhr Industries, Williamston, MI).

Formulation	Engine speed (rpm)	Rate per atomizer (gal/min)[z]	Droplet size[y]		
			$D_{V0.1}$ (µm ± SD)	$D_{V0.5}$ (µm ± SD)	$D_{V0.9}$ (µm ± SD)
Water	5100	0.36	29.4 ± 0.8	98.4 ± 5.7	161.2 ± 13.6
Water + 0.25% NIS[x]	5100	0.36	33.0 ± 4.2	94.9 ± 15.8	193.0 ± 21.6
Malathion	3500	0.36	33.7 ± 1.6	91.6 ± 4.0	173.6 ± 3.8
Spinetoram	5100	0.36	32.6 ± 2.0	97.6 ± 5.9	165.8 ± 7.0
Diflubenzuron	5100	0.36	31.6 ± 1.1	93.8 ± 3.8	172.9 ± 4.1
Fenpropathrin	3500	0.36	34.5 ± 0.4	96.4 ± 2.1	209.5 ± 11.1

[z]1 gal = 3.7854 L.
[y]$D_{V.01}$, $D_{V.05}$, and $D_{V.09}$= the droplet diameter where 10%, 50%, and 90%, respectively, of the spray volume is contained in droplets smaller than this value. Values represent the mean of three replications; 1 µm = 1 micron.
[x]NIS = nonionic surfactant (R-11; Wilbur-Ellis, Walnut Creek, CA).

general sprayer model performance. For each machine tested, the droplet size under the initial operational settings is presented followed by the droplet size at the adjusted settings. Typically, for the LV-8 and LV-8-V2, decreasing the engine rpm resulted in increased droplet size such the 90-µm size requirement was met. There were several of the LV-8 machines that, even with maximum reduction of the engine speed, the 90-µm level was not met. Each of the individual machines tested had unique lower engine speed, again due to variability in machine age, maintenance, and level of modification. For the LV-8-V1 machines tested, similar adjustments in engine speed did not result in sufficient increase in droplet size. The LV-8-V1 has a smaller pump and small diameter tubing leading to each of the spray nozzles, which limits flow output and thereby the ability to generate larger droplets.

The London Fog model 18–20 citrus sprayers followed similar trends

Table 5. Spray droplet size measurements from sprayers in the citrus spray calibration rodeo with the original setting results followed by the adjusted setting results for a water plus nonionic surfactant solution. The sprayers were adjusted to comply with the droplet size requirements of the Special Local Needs permits granted to some insecticides in the State of Florida.

			Original settings				Droplet size in first test[x]		
Sprayer[z]	Model no.	Nozzle[z]	Spray rate (gal/acre)[y]	Liquid pressure (psi)[y]	Air pressure (psi)	Engine speed (rpm)	$D_{V0.1}$ (µm ± SD)	$D_{V0.5}$ (µm ± SD)	$D_{V0.9}$ (µm ± SD)
Adapco	190GS	Standard	2		3	2800	17.2 ± 1.5	51.1 ± 5.8	121.4 ± 13.8
AirTec	CAB1000	Albuz	25	70		540 - PTO[w]	37.3 ± 0.3	99 ± 1.2	173.7 ± 4.5
Curtec	648 D	Curtec coarse	10			2100	30.4 ± 0.4	75.5 ± 0.8	133.8 ± 2.3
Curtec	648 D	Curtec fine	10			1500	31.6 ± 1.0	87.1 ± 3.7	159.7 ± 17.6
Curtec	C3000	Curtec coarse	21	15		540 - PTO	27 ± 0.4	70.9 ± 0.6	130.6 ± 4.2
Curtec	P400D	Proptec coarse	2	2		2100	63.2 ± 4.8	149.2 ± 12.2	335.8 ± 79.7
London Fog	2D MaxiPro	Standard	2	1 gal/min[y]	4	2500	17.6 ± 0.2	38.4 ± 0.1	79.4 ± 6.2
ESS	MaxCharge ESS100	Standard	15	20	30	440 - PTO	14.3 ± 0.3	41.9 ± 0.3	102.9 ± 1.1
Proptec		Proptec coarse	3		7	1700	31.5 ± 1.8	75.5 ± 6.7	147.3 ± 28.1
Proptec		Proptec fine	3		8	1700	31.6 ± 0.4	80.7 ± 4.2	139.3 ± 4.5
Rears	PulBlast	Rotary	5	50		2500	131.6 ± 8.3	278.9 ± 16.9	390.7 ± 25.7
Rears	PulBlast	Albuz ATR-80	5	150		450 - PTO	56.4 ± 0.8	131.4 ± 0.4	214.9 ± 1.0
Sides	Spectrum	Ogee shear	10	42		1700	38.6 ± 2.3	99.7 ± 8.2	184.8 ± 27.4

				Adjusted settings			Droplet size after adjusting sprayer[x]		
Sprayer	Model no.	Nozzle	Targeted rate (gal/acre)	Liquid pressure (psi)	Air pressure (psi)	Engine speed (rpm)	$D_{V0.1}$ (µm ± SD)	$D_{V0.5}$ (µm ± SD)	$D_{V0.9}$ (µm ± SD)
Adapco	190GS	Standard	2	0	3	1900	39.2 ± 1.1	107.6 ± 4.5	227.2 ± 14.8
Curtec	648 D	Curtec coarse	10			1500	31.9 ± 0.8	79.1 ± 1.8	142.1 ± 4.5
Curtec	C3000	Curtec coarse	21	15	0	440 - PTO	33.3 ± 2.1	95.7 ± 2.7	180.2 ± 1.0
London Fog	2D MaxiPro	Standard	2	1 gal/min	4	1640	29.4 ± 2.1	76.7 ± 5.6	177 ± 11.5
ESS	MaxCharge ESS100	Standard	15	30	25	540 - PTO	13.3 ± 0.5	34.7 ± 1.4	83.9 ± 3.0
Proptec		Proptec coarse	5	0	7	1300	31.3 ± 1.8	75.5 ± 6.7	147.3 ± 28.1
Proptec		Proptec fine	5	0	7	1300	37.4 ± 2.0	88.7 ± 3.6	162.9 ± 13.1

[z]Adapco (Sanford, FL); AirTec (AirTec Sprayers, Winter Haven, FL); Curtec (Curtec of Florida, Vero Beach, FL); London Fog (Long Lake, MN); ESS (Electrostatic Spraying Systems, Watkinsville, GA); Proptec (Ledebuhr Industries, Williamston, MI); Rears (Rears Manufacturing, Eugene, OR); Sides (Goldthwaite, TX); Albuz (Spirit River, AB, Canada); Ogee (Spectrum Electrostatic Sprayers, Houston).
[y]1 gal/acre = 9.3540 L·ha^{-1}, 1 psi = 6.8948 kPa, 1 gal = 3.7854 L.
[x]$D_{V.01}$, $D_{V.05}$, and $D_{V.09}$= the droplet diameter where 10%, 50%, and 90%, respectively, of the spray volume is contained in droplets smaller than this value. Values represent the mean of three replications; 1 µm = 1 micron.
[w]Power take-off.

as the LV-8s. With a single exception, reducing the engine speed increased $D_{V0.5}$ values such that the 90-µm size requirement was met.

Conclusions

In response to the need for accurate droplet size assessments of application equipment used in the control of the asian citrus psyllid in Florida, a variety of field application sprayers were evaluated to determine if the applied sprays met the Special Local Needs labeling requirements of volume median diameters of 90 µm or greater. Initially, a series of studies was conducted across three typical spray systems and five a.i. to determine typical machine operating characteristics and resulting droplet sizes. From these tests, it was found that for typical air-blast type sprayers, reductions in engine speed were required to reduce air-shear atomization to increase droplet sizes to the required size. For air-assisted sprayers, this also held true with the addition that increased flow rate also potentially increased droplet size. Following these initial assessments, a series of droplet sizing rodeos were held in Florida to measure spray droplet size from applicator- and grower-owned citrus sprayers operating in "as-is" conditions. Based on the resulting spray droplet size, the sprayer settings were adjusted such that the resulting droplet size would comply with the label requirements. Following the trends seen in the initial round of testing, the majority of the sprayers was adjusted via the engine speed or spray pressure such that the resulting spray's volume median diameter was greater than or equal to 90 µm. As the equipment tested here represent the most typical application equipment used in Florida for asian citrus psyllid control, these results will provide applicators, growers, and extension agents with general guidelines to insure that spray systems are operated in a manner that complies with label restrictions.

Table 6. Spray droplet size measurements for Curtis Dyna-Fog LV8 (Curtis Dyna-Fog, Westfield, IN) and London Fog model 18–20 (London Fog, Long Lake, MN) sprayers in the citrus spray calibration rodeo with original setting results followed by the adjusted setting results for a water plus nonionic surfactant solution. The sprayers were adjusted to comply with the droplet size requirements of the Special Local Needs permits granted to some insecticides in the State of Florida.

				Original settings				Results after adjusting sprayer			
					Droplet size[x]				Droplet size[x]		
Sprayer	Model no.[z]	Spray rate (gal/acre)[y]	Air pressure (psi)[y]	Engine speed (rpm)	$D_{V0.1}$ (µm ± SD)	$D_{V0.5}$ (µm ± SD)	$D_{V0.9}$ (µm ± SD)	Engine speed (rpm)	$D_{V0.1}$ (µm ± SD)	$D_{V0.5}$ (µm ± SD)	$D_{V0.9}$ (µm ± SD)
Dyna-Fog	LV8	3	6	2260	23.6 ± 3.9	64.5 ± 11.9	130.6 ± 23.9	2260	29.7 ± 1.1	87.8 ± 0.9	219.5 ± 19.7
Dyna-Fog	LV8	5	6	2500	21.1 ± 2.7	55.5 ± 6.4	112.9 ± 11.4	1800	27.3 ± 0.3	71.8 ± 0.4	151.4 ± 1.2
Dyna-Fog	LV8	3.5	10	2500	16.1 ± 1.6	47.1 ± 3.3	101.7 ± 3.5	1350	33.5 ± 1.1	95.5 ± 6.9	240.1 ± 11.1
Dyna-Fog	LV8	2.5	8	2600	15.8 ± 0.9	39.6 ± 2.1	79.8 ± 7	2100	28.6 ± 0.6	73.3 ± 2.9	154.8 ± 2.8
Dyna-Fog	LV8	3	7	2600	20.4 ± 0.6	53.1 ± 2.7	106.3 ± 10.3	1800	34.1 ± 0.9	98.9 ± 4.8	197.3 ± 24.9
Dyna-Fog	LV8	2.4	9	2600	22.4 ± 0.1	64.1 ± 2.1	131.5 ± 16.5	2040	37.3 ± 2.3	113.7 ± 11.9	239.5 ± 33.7
Dyna-Fog	LV8	3	9	2600	24.8 ± 0.4	76 ± 4.7	185.4 ± 0.1	1400	42.2 ± 1.7	123.8 ± 13.9	277.3 ± 62.7
Dyna-Fog	LV8	3	9	2600	26.5 ± 2.1	76.8 ± 4.4	176.3 ± 19.2	2120	35.2 ± 0.7	107.2 ± 4.0	226.8 ± 11.0
Dyna-Fog	LV8	3	6	2140	24.4 ± 0.7	69.8 ± 2.3	160.9 ± 8.3	2000	31.1 ± 0.1	98.8 ± 2.7	242.3 ± 38.9
Dyna-Fog	LV8-V1	2	7	2600	14.6 ± 0.8	50.1 ± 12.7	157.9 ± 31.3	1600	21.5 ± 0.4	55.6 ± 0.5	117.4 ± 2.4
Dyna-Fog	LV8-V1	3	6	1670	18.3 ± 0.7	44.2 ± 2.1	90 ± 1.4	1350	22.1 ± 1.6	56.1 ± 3.8	112.2 ± 12.8
Dyna-Fog	LV8-V1	1	7	2600	13.2 ± 1.8	35.3 ± 1.7	69.2 ± 4.3	2300	17.5 ± 0.5	44.8 ± 0.2	88.1 ± 2.5
Dyna-Fog	LV8-V1	2	7	2600	14.2 ± 0.8	35.4 ± 1.9	70.9 ± 5.3	2000	17.2 ± 0.4	45.7 ± 1.9	93.5 ± 7.6
Dyna-Fog	LV8-V2	5	7	2500	27.2 ± 1.6	76.7 ± 1.5	166.7 ± 21.4	2020	33.1 ± 2.6	97.3 ± 1.8	234.2 ± 16.0
London Fog	18–20	0.4		2600	12.4 ± 0.6	25.9 ± 2.0	57.1 ± 18.4	1900	24.1 ± 1.1	61.1 ± 2.5	104.2 ± 4.5
London Fog	18–20	1		2850	18.9 ± 0.1	46.8 ± 0.1	85.0 ± 0.3	1800	37.0 ± 0.4	90.3 ± 1.9	167.0 ± 9.6
London Fog	18–20	2	7	2720	22.8 ± 0.7	62.0 ± 0.1	130.6 ± 3.5	1800	48.1 ± 0.8	117.9 ± 0.1	237.8 ± 4.0
London Fog	18–20	1.8		2600	31.6 ± 1.6	83.1 ± 3.7	177.9 ± 13.9	2400	35.8 ± 2.3	96.1 ± 3.1	202.4 ± 15.8
London Fog	18–20	1.8		2600	32.2 ± 2.6	89.9 ± 4.0	190.2 ± 4.4	2400	30.2 ± 0.6	93.2 ± 3.4	221.6 ± 26.7
London Fog	18–20	3	4	2500	24.9 ± 5.6	65.1 ± 17.7	134.7 ± 23.8	1500	49.1 ± 1.9	124.4 ± 6.1	246.5 ± 7.6

[z]LV8 and LV8-V2 have 3/8- to 1/2-inch tubing to each nozzle, LV8-V1 has 1/8-inch tubing to each nozzle; 1 inch = 2.54 cm.

[y]1 gal/acre = 9.3540 $L \cdot ha^{-1}$; 1 psi = 6.8948 kPa.

[x]$D_{V.01}$, $D_{V.05}$, and $D_{V.09}$= the droplet diameter where 10%, 50%, and 90%, respectively, of the spray volume is contained in droplets smaller than this value. Values represent the mean of three replications; 1 µm = 1 micron.

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Appendix

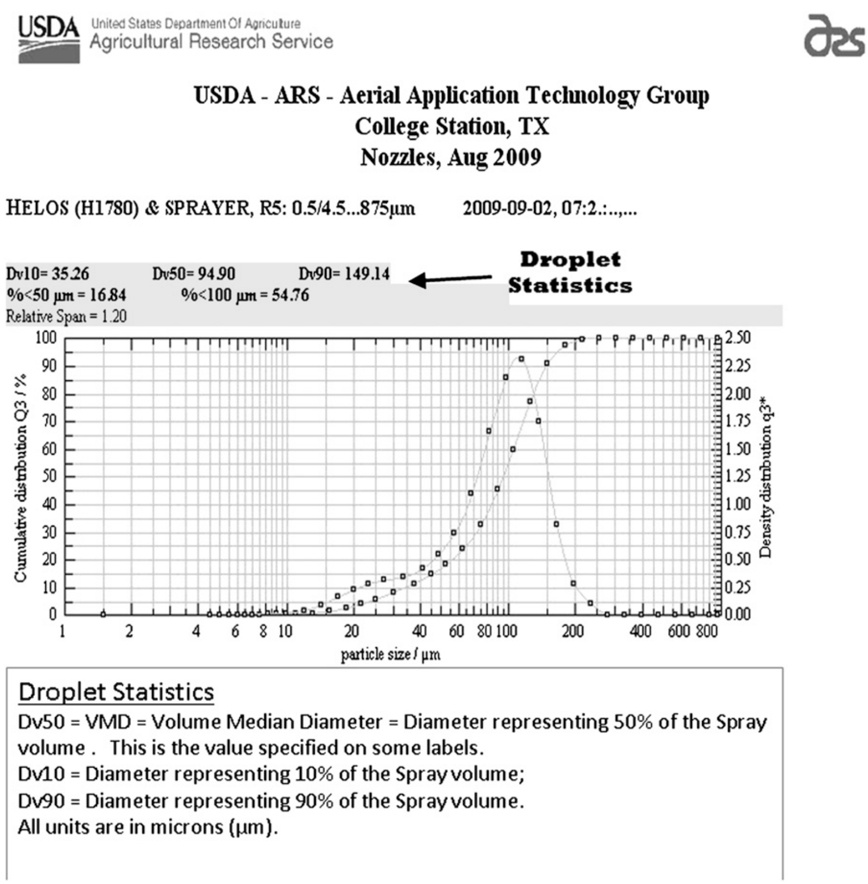

Fig. 2. Handout given to applicators at the citrus sprayer calibration rodeos to explain the results of the tests; 1 µm = 1 micron, 1 gal = 3.7854 L, 1 psi = 6.8948 kPa, 1 m/s = 1 m·S^{-1} = 2.2369 mph.