Pesticide Spraying in Indian River Grapefruit: I. Survey of Current Practices

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SUMMARY. Pesticide spray practices for citrus (*Citrus* spp.) in the Indian River region of Florida were surveyed in 2001 as the first step in identifying opportunities for improving efficiency and reducing potential environmental impact. The survey covered 73% of grapefruit (*C. paradisi*) acreage in Indian River, St. Lucie, Martin and Palm Beach counties, comprising 70% of all Indian River commercial grapefruit. Large differences in spray practices were revealed. The focus of this survey was grapefruit spraying, since grapefruit represent 59% of fresh citrus shipped from the Indian River region, and are sprayed more intensively than citrus fruit grown for processing. In commercial groves, almost all foliar sprays to grapefruit are applied using air-assisted sprayers pulled through the groves by tractors. Use of engine-driven and power-take-off-driven sprayers were reported with equal frequency and accounted for 89% of spray machines used. Low-volume Curtec sprayers comprised the remainder. Spray volume for grapefruit varied: 7.6% of acreage was sprayed at 25 to 35 gal/acre (230 to 330 L·ha⁻¹) for all sprays; 4.2% was sprayed at 100 to 170 gal/acre (940 to 1600 L·ha⁻¹) for all sprays; 15.3% was sprayed at 200 to 380 gal/acre (1900 to 3600 L·ha⁻¹) for all sprays; 28.2% was sprayed at 450 to 750 gal/acre (4200 to 7000 L·ha⁻¹) for all sprays; and 44.5% of grapefruit acreage was sprayed in a progressive manner from lower to higher volume as the season progresses. Many mid and high spray volume growers reported unacceptable results when they lowered spray volume. Although

correlation was moderate ($r = 0.35$ to 0.45), regressions indicated that both total foliar pesticide spray material costs, and annual fungicidal copper (Cu) use increased with spray volume used for postbloom fungicides. Mean Cu use per acre was in the middle of the recommended range. All growers reported adjusting nozzling for tree height within a grove, and since Indian River groves are bedded, growers adjusted sprayer output differently for trees on bed tops versus furrows on 85% of acreage. Sprayers were shut off for missing trees on 83% of acreage, but this was done only for two or more adjacent trees on almost half of this area. Sensor-actuated sprayers were used to minimize off-target application on 14.7% of grapefruit acreage, but for an additional 21% of acreage, growers reported trying and abandoning this technology. While 88% of grove acreage was sprayed during the day, 75% of acreage sprayed using less than 100 gal/acre was sprayed at night. Growers reported no defined protocol for ceasing spray operations based on environmental conditions.

Foliar spray applications are used to control an array of important pests in the Indian River citrus growing region of Florida. While fruit grown for processing may only require one or two sprays each year, fresh market citrus typically receives additional sprays (Muraro et al., 1999) to reduce fruit blemishes. Grapefruit represent 59% of fresh citrus fruit shipped from this region (Florida Department of Agriculture and Consumer Services, 2000) and these fruit are especially susceptible to several diseases that affect rind appearance. These diseases typically result in a substantial proportion of fruit (15% to 20%) being rejected for packing as fresh fruit (Miller and Burns, 1992), with less than 50% of annual production suitable for fresh sales in the current market (Florida Agricultural Statistics Service, 2000).

Aerial application, using fixed-wing aircraft or helicopter-mounted sprayers, is used for some sprays when good coverage is less important [nutritional sprays or sulfur applications for citrus rust mites (*Phyllocoptruta oleivora*)] or for occasional sprays when wet water furrows prevent use of ground equipment. However, almost all foliar applications to grapefruit trees in commercial groves are made using air-assisted sprayers pulled through the

groves by tractors. Therefore, current practices using tractor-drawn sprayers were the focus of this survey.

Several factors have provided the rationale for intensive assessment of spray application practices. Oversupply of grapefruit permits buyers to demand exceptionally clean fruit in the fresh pack, making spray efficacy of great importance for premium markets, while low overall prices encourage scrutiny of all inputs to identify opportunities for savings. Moreover, concern about surface water contamination with some spray materials has focused attention on practices that may decrease off-target deposition. This study of current spray practices in the Indian River citrus region was conducted as a first step in identifying opportunities for improving efficiency and reducing potential environmental impact.

Materials and methods

Forty growers and spray contractors were interviewed from March through May 2001 using a standard survey format. Because spray contractors service many individual groves, the survey actually represents practices for a total of 191 individual growers. The data were collected for commercial groves in Indian River, St. Lucie, Martin and Palm Beach counties, which comprise more than 90% of the grove area in the legally defined Indian River Citrus Production Region (Florida Agricultural Statistics Service, 2000). According to the State of Florida's statistics there are 214,028 acres (86,600 ha) bearing citrus in these four counties and 80,983 acres (32,800 ha) bearing grapefruit (Florida Agricultural Statistics Service, 2000). The data collected represent production practices on 128,936 acres (52,200 ha) or 60% of the total citrus acreage and 59,084 acres (23,900 ha) of grapefruit or 73% of the total bearing grapefruit acreage in these counties and 71% of all Indian River grapefruit acreage (Florida Agricultural Statistics Service, 2001).

The survey included a broad array of questions relating to foliar spray practice components as well as information identifying area and types of citrus farmed by the respondents. Survey questions included: acres in citrus; number and type of spray machines; typical nozzle number and sizes; ground speed and pressure used for

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Florida Agricultural Experiment Station journal series R-08454.

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sprayers; gallons per acre used on various fresh grapefruit sprays; practices for spraying row ends; meteorological conditions necessary to alter or postpone sprays; approaches used for tailoring sprays to specific blocks; and use of tree sensor technology. The responses were examined for natural clustering of data and categorized into groups, therefore, in this study very low volume was defined as application at 25 to 35 gal/acre; low volume was defined as 100 to 170 gal/acre; middle volume was defined as 200 to 380 gal/acre; and high volume was defined as 450 to 750 gal/acre.

These interviews were conducted in part to facilitate implementation of pesticide best management practices (BMPs) for the Indian River citrus region, so additional related issues were discussed, and growers often chose to explain the rationale for their practices. Ancillary information was collected that suggested important trends but lacked the broad representation obtained for survey questions. Thirty seven of the original 40 respondents provided further information about number of sprays containing Cu, amount of Cu used per acre, tree size and age, and use of tower sprayers. This information is also reported in the analysis. Regression analyses were conducted using Excel 2000 (Microsoft Corp., Redmond, Wash.).

Results and discussion

SPRAY EQUIPMENT. Three main types of sprayers are used in commercial Florida citrus production. Two types of airblast sprayer are standard for mid- and high-volume applications: the engine-driven and the power-take-off (PTO)-driven airblast sprayers. These are essentially identical in function but differ in power source. The third type of sprayer has very low-volume output and is represented in this survey exclusively by Curtec machines (BEI, Inc., South Haven, Mich.). The Curtec is also an air-assist sprayer but differs from the airblast machines in several important ways. Curtecs produce a narrower range of smaller droplets [with a volume median diameter (VMD) of about 120 μm (M. Salyani, unpublished)] than standard airblast sprayers (droplet size range of 5 to 600 μm) (Steiner, 1977). The air delivery system also differs in that the air is directed at the canopy by three or four stacked cross-flow fans

instead of radiating outward from one axial-flow fan. The fans and accompanying rotary atomizers are arrayed on booms ranging from 15.5 to 16.8 ft (4.7 to 5.1 m) in height in the Curtec sprayer. While airblast tower sprayers are available, only two respondents use such equipment.

Engine-driven and power PTO-driven airblast sprayers were reported with equal frequency and accounted for 89% of spray machines, with very low-volume (Curtec) machines comprising the remainder. Forty percent of respondents had more than one type of sprayer, while the remaining 60% had a single type of sprayer. Twenty-five percent of respondents used both the Curtec and one or more of the airblast sprayer types. Frequently, operations with more than one sprayer type designated specific sprayers for different types of sprays or for different varieties. In addition, the depth and condition of the water furrows may be a factor in choosing a specific sprayer type since weight, center of gravity, and tire flotation can all affect ability to enter, exit and drive through wet and/or deep furrows.

Growers with both Curtec and airblast sprayers diverged significantly in their use. Four out of the 10 who use both types use the Curtec sprayer for most of their fresh grapefruit sprays. The other six growers with both Curtec and airblast machines largely reserve the Curtec sprayers for juice oranges (*Citrus sinensis*) since they have experienced significant burn or reduced packout when low-volume machines were used for Cu applications on fresh fruit. However, these growers report use of Curtec machines for fresh fruit sprays where good coverage is not needed or spray burn is not likely. Growers who confidently use Curtec machines for fresh fruit see lower application cost per acre as a major advantage. They reported some problems with spray burn but made adjustments and found satisfactory solutions.

It should be noted that perception of spray burn severity can be highly subjective. The extent of burn is likely to be exaggerated when viewed in the grove, since most burn symptoms occur on exterior fruit exposed to both high levels of spray materials and sunlight (Albrigo and Grosser, 1996). Since growers seldom rigorously compare different spray programs, conclusions based on percentage of fruit accepted for fresh

sales (pack-out) can also be misleading, since many things can effect packout that are independent of spray practices (Miller and Burns, 1992).

SPRAY VOLUME. Growers were asked to specify the gallons per acre used in three general spray periods focusing on fungal pathogens for fresh grapefruit: dormant, postbloom and summer oil. These periods were chosen because they provide the basic framework for the fresh grapefruit spray schedule. Additional sprays for mites [citrus rust mite, citrus red mite (*Panonychus citri*), six-spotted spider mite (*Eotetranychus sexmaculatus*), texas citrus mite (*Eutetranychus banksi*), and more rarely broad mite (*Polyphagotarsonemus latus*)], insects, and nutritional purposes may also be applied as needed (Bullock et al., 1977). The first fungicide spray in most grapefruit blocks is primarily directed toward citrus scab (caused by *Elsinoë fawcettii*) and may be omitted in blocks with little evidence of this disease. This spray is applied around two-thirds petal fall (Timmer, 2001b). Some growers begin their Cu sprays at this time in order to cover the few small fruit that are already exposed to melanose (caused by *Diaporthe citri*). Most fresh grapefruit growers use two to five postbloom sprays to control melanose from petal fall to early July when the fruit becomes less susceptible (Timmer, 2001a). Often the last melanose spray is also directed toward greasy spot (caused by *Mycosphaerella citri*), with one to two sprays of Cu with oil typically applied in the summer to control this disease. Cu fungicides have been the mainstay for all of these sprays, supplemented by petroleum oils in the summer, but other fungicides are also labeled for each of the diseases mentioned. Since Cu acts as a protectant it must be applied prior to the infection period and it must be distributed uniformly throughout the canopy on both leaves and fruit (Whiteside, 1977).

Selection of spray volume involves a balance of several factors. For any spray equipment, more acreage can be covered per day by reducing spray volume rate and thus increasing the proportion of time spraying versus filling the sprayer. However, efficacy of materials requires adequate volume for coverage of fruit and foliage in the actual field conditions during the spray, and is strongly influenced by canopy architecture, environmental condi-

Table 1. Spray volumes reported for Indian River grapefruit production in 2001 survey. This represented 76% of all grapefruit acreage in Indian River, St. Lucie, Martin and Palm Beach counties, comprising a majority of the grapefruit production in the legally defined Indian River Citrus Production Region.

Spray vol reported ^a	Proportion of grapefruit acreage (%)	Proportion of growers (%)
Very low for all sprays	7.6	1.5
Low for all sprays	4.2	1.5
Middle for all sprays	15.3	56
High for all sprays	28.2	13
Varying among spray periods	44.5	28

^aSpray volume: very low = 25–35 gal/acre (230–330 L·ha⁻¹), low = 100–170 gal/acre (940–1600 L·ha⁻¹), middle = 200–380 gal/acre (1900–3600 L·ha⁻¹), high = 450–750 gal/acre (4200–7000 L·ha⁻¹).

tions, sprayer design, and sprayer setup (Carman, 1977; Derksen and Gray, 1995; Hall, 1991; Hoffman and Salyani, 1996). As recently as 1975, a standard spray application for Florida citrus was 2000 gal/acre (18,800 L·ha⁻¹) for large trees (Cromwell, 1975). All respondents were well below this value. Growers interviewed varied widely in the spray volumes used, with their selections based on their individual equipment, tree size, experience, and aversion to risk.

Spray volume use for grapefruit production was reported (Table 1) with less than 8% of acreage sprayed at 25 to 35 gal/acre for all sprays; 4% sprayed at 100 to 170 gal/acre for all sprays; 15% sprayed at 200 to 380 gal/acre for all sprays; 28% sprayed at 450 to 750 gal/acre for all sprays; while 44% of grapefruit acreage is sprayed in a progressive manner from lower to higher volume as the season progresses. This last category is comprised of three subcategories: 34% of grapefruit acreage is sprayed at 200 to 380 gal/acre for dormant and/or postbloom but higher for oil; 4% of grapefruit acreage is sprayed at 100 to 170 gal/acre for dormant and/or postbloom but higher for oil; and 6% of grapefruit acreage is sprayed at 25 to 35 gal/acre for dormant and/or postbloom but higher for oil. Mid-volume sprays (200 to 380 gal/acre) are used by most of the spray contractors interviewed.

Growers who vary spray volume

attempt to balance efficiency with coverage adequate to control the principal pests in each spray period. Many growers/applicators indicated that full coverage is less critical on the first spray, directed mainly at citrus scab, and therefore lower spray volumes are often used. The second set(s) of sprays, for melanose control, use higher volume since good coverage of interior fruit is considered important for this disease. Finally, many growers reported even higher volumes for summer oil sprays. Some growers who used Curtec sprayers for other sprays shifted to airblast sprayers for summer oil applications, which are directed at mite (primarily citrus rust mite) and scale insect [over 40 species infest Florida citrus, the most important include: florida red scale (*Chrysomphalus aonidum*), soft brown scale (*Coccus hesperidum*), purple scale (*Cornuaspis beckii*), cottoncushion scale (*Icerya purchasi*), glover scale (*Lepidosaphes gloveri*), chaff scale (*Parlatoria pergandii*), caribbean black scale (*Saissetia neglecta*), and citrus snow scale (*Unaspis citri*)] control in addition to greasy spot. Since petroleum oil controls these arthropod pests by functioning as a suffocant, higher volume applications are considered necessary for thorough coverage (Brooks and Whitney, 1971). Details are listed in Table 2.

Many growers using mid- to high-volume applications have tried lower gallonage but reported poor coverage

or lower packout and remain skeptical of spray volume reduction. Interestingly, one third of the operations routinely using low volume for their citrus scab and melanose sprays also pack the fruit that they produce. It is possible that disconnection between industry elements and other characteristics of industry structure hamper shifts into less proven technology. For example, ultimate decision makers for many corporations often have little production experience and may construe unrelated reductions in packout as resulting from adoption of unproven practices. One production manager of a large company is cautiously reducing his spray volume over a period of several years on part of his acreage, and is closely monitoring any complaints that might come from the packing house.

ACREAGE PER SPRAYER AS INFLUENCED BY TYPICAL SPRAY VOLUME.

One rationale for use of lower spray volumes is that fewer spray machines may be needed to cover similar acreage. The ratio of spray machines to grapefruit acreage was compared across spray volume categories for the postbloom sprays, since this is the period when sprayer use is most intensive. Several respondent outliers were excluded, such as owners of small acreage with a single sprayer. The breakdown by volume categories for postbloom sprays is indicated in Table 3.

Examination of acres per sprayer

Table 2. Spray volumes for individual spray periods reported for Indian River grapefruit production in 2001 survey representing 76% of all grapefruit in Indian River, St. Lucie, Martin and Palm Beach counties.

Spray period	Proportion of grove acreage receiving reported spray vol (%)			
	Very low spray vol ^a	Low spray vol ^b	Middle spray vol ^c	High spray vol ^w
Dormant (prebloom to 2/3 petal fall)	13.9	27.4	30	28
Postbloom	13.8	8.4	50.7	28
Summer oil	7.6	4.2	21	66.5

^aSpray volume: very low = 25–35 gal/acre (230–330 L·ha⁻¹), low = 100–170 gal/acre (940–1600 L·ha⁻¹), middle = 200–380 gal/acre (1900–3600 L·ha⁻¹), high = 450–750 gal/acre (4200–7000 L·ha⁻¹).

Table 3. Spray machines per acre, pounds metallic copper (Cu) and total foliar pesticide cost (excludes herbicides) per acre per year reported for Indian River grapefruit production in 2001 survey.

Spray vol ^z	Spray machines (no./acre)		Fungicidal Cu applied (lb/acre/year) ^y		Foliar pesticide costs (\$/acre per year)	
	Acreage-weighted avg	Range	Acreage-weighted avg	Range	Acreage-weighted avg	Range
Overall	259	85–1078	10.1	5.5–16.7	248	150–350
Very low	435	333–1078	8.1	5.8–10.6	200	150–280
Low	201	125–620	9.9	9.4–12.0	294	250–300
Middle	236	85–528	9.3	5.5–16.0	258	180–350
High	304	100–382	13.3	7.5–16.7	293	230–350
<i>r</i> value for regressions ^x	0.32		0.41		0.44	

^zSpray volume: very low = 25–35 gal/acre (230–330 L·ha⁻¹), low = 100–170 gal/acre (940–1600 L·ha⁻¹), middle = 200–380 gal/acre (1900–3600 L·ha⁻¹), high = 450–750 gal/acre (4200–7000 L·ha⁻¹)

^yElemental copper regardless of formulation, 1.0 lb/acre = 1.12 kg·ha⁻¹

^xRegressions were conducted between gallons per acre for postbloom sprays and the following data: sprayers per acre, pounds metallic copper and foliar pesticide costs. All regressions were positive (*P* = 0.06, 0.01, and 0.03 respectively).

by volume category suggests that the greatest difference is between users of Curtec sprayers and airblast units. Overall, operations using airblast sprayers for postbloom sprays averaged one sprayer for every 244 acres (99 ha) of grapefruit, while those who used Curtec sprayers averaged one machine for every 435 acres (176 ha). Linear regression between spray volume for postbloom grapefruit sprays and acres covered per sprayer was significant with *r* = 0.32. There were also anecdotal reports supporting the idea of more acres per sprayer at low volume. In the most extreme case, one grower replaced five airblast sprayers with a single Curtec machine for postbloom sprays. Driven by these efficiencies in application, the trend is clearly toward lower spray volumes, with several growers expressing frustration at not being successful in their attempts to move from mid- to low-volume sprays.

COPPER USAGE PER ACRE AS INFLUENCED BY TYPICAL SPRAY VOLUME.

There was tremendous variability in number of Cu sprays applied postbloom (two to five) with some mid- and high-volume users spraying more often than some of those using lower volume. The high-volume sprayers (450 to 750 gal/acre) used an acreage-weighted average of 3.5 Cu sprays per year while very low- and low-volume (25 to 170 gal/acre) sprayers used an average of five sprays, with intermediate number of applications for the mid-volume sprayers. However, correlation between postbloom spray volume and number of sprays including Cu was weak.

Informal discussions during the survey interviews indicated a strong tendency for less total Cu application

in organizations that used low-volume sprays. Thirty-seven growers (representing 96% of surveyed acreage) provided additional information on Cu use. All values were expressed as pounds of Cu per acre, to avoid confusion over different levels of active ingredient (Table 3). Two growers severely limited spray application for economic reasons, using 2 to 3 lb/acre (2.2 to 3.4 kg·ha⁻¹) of total Cu per year. These atypical values were excluded from the following calculations. On an acreage-weighted basis, the very low-volume spray growers averaged 8.1 lb/acre (9.1 kg·ha⁻¹) of Cu per year with a range of 5.8 to 10.6 lb/acre (6.5 to 11.9 kg·ha⁻¹); low-volume spray growers averaged 9.9 lb/acre (11.1 kg·ha⁻¹) of Cu per year with a range of 9.4 to 12.0 lb/acre (10.5 to 13.5 kg·ha⁻¹); mid-volume spray growers averaged 9.3 lb/acre (10.4 kg·ha⁻¹) of Cu per year with a range of 5.5 to 16.0 lb/acre (6.2 to 17.9 kg·ha⁻¹); and high-volume sprayers averaged 13.3 lb/acre (14.9 kg·ha⁻¹) of Cu per year with a range of 7.5 to 16.7 lb/acre (8.4 to 18.7 kg·ha⁻¹).

Overall the average Cu use by growers spraying at very low through middle volumes was 30% to 34% less than by high-volume spray growers. A regression of gallons per acre for postbloom sprays versus pounds of Cu per acre was significant and positive but the correlation was only moderate (*r* = 0.41). The acreage-weighted average was 10.1 lb/acre (11.3 kg·ha⁻¹) of Cu per year, which is centered within the guidelines recommended for control of fungal diseases on Florida grapefruit [8 to 12 lb/acre (9.0 to 13.4 kg·ha⁻¹)] (Timmer, 2001a).

Growers using very low-volume sprayers indicated that they reduced Cu concentrations to control spray burn. More frequent sprays are then considered necessary to maintain coverage following weathering and to compensate for deposition variability associated with low spray volume. There may be several additional benefits from this approach. Melanose control depends on sufficient Cu coverage of fruit prior to infection-triggering rain events, and lower rates with more frequent applications should reduce the proportion of time in which fruit are unprotected (Albrigo and Timmer, 1997). It is also argued that lower volume spray applications should permit equal efficacy with lower chemical rates because of better distribution from small droplet sizes and reduced runoff from foliage (Steiner, 1977).

CHEMICAL COST. Growers were asked to provide their chemical cost on a per acre basis for the previous year's fresh grapefruit crop (Table 3). Some growers did not share cost data and others provided an estimate. Responses ranged from \$65 to \$350/acre (\$161 to \$865/ha) and averaged \$248/acre (\$613/ha) on an acreage-weighted basis. Four growers reported chemical costs between \$65 and \$100/acre (\$161 to \$247/ha) and were excluded from further analyses as outliers. Growers spraying at very low volume reported an acreage weighted mean of \$200/acre (\$494/ha) versus \$294/acre (\$726/ha) for low volume, \$258/acre (\$637/ha) for middle volume, and \$293/acre (\$724/ha) at high volume. The broad cost ranges reported probably reflect differences in materials used such as more expensive

Table 4. Nozzle configurations reported for airblast sprayers in the 2001 survey of Indian River grapefruit producers.

Spray volume ²	Nozzles/side (no.)	Range in nozzles/side (no.)	Range in disc sizes (TeeJet no.) ³	Range in nozzle core hole number
Overall	14	8–27	3–10	2–5
Low	13	8–20	3–5	2–3
Middle	13	8–27	3–10	2–5
High	17	10–24	3–9	2–4

²Spray volume: low = 100–170 gal/acre (940–1600 L·ha⁻¹), middle = 200–380 gal/acre (1900–3600 L·ha⁻¹), high = 450–750 gal/acre (4200–7000 L·ha⁻¹)

³Spraying Systems Co., Wheaton, Ill.

newer materials versus sprays of Cu, oil, and sulfur only. A published estimate for spray material costs for 1998–99 Indian River grapefruit was \$196.90/acre (\$486.53/ha), based on five typical sprays (Muraro et al., 1999). In this survey, the relationship between chemical cost per acre and spray volume per acre in the postbloom period was positive and significant but overall correlation was moderate ($r = 0.42$). Lower spray material costs reported by Curtec users appears to largely explain this correlation, and may be consistent with a philosophy of reducing production costs through greater risk tolerance.

CORRELATION BETWEEN SPRAY VOLUME AND TREE SIZE. Comments during the initial survey revealed many growers using high-volume applications on tall trees [18 to 22 ft (5.5 to 6.7 m)], while growers using lower spray volume were often controlling tree height by topping at 12 to 14 ft (3.7 to 4.3 m). More information on tree height was collected and indicated some relationship between grower management of tree size and spray volume, but with considerable variability. All growers that reported spraying trees taller than 20 ft (6.0 m) sprayed in the mid or high volume range. However there were low-volume sprays applied to trees up to 20 ft and some growers sprayed at a high volume on trees less than 20 ft. One respondent illustrated the variability in grower spray practice quite well: he sprayed his own trees up to 20 ft tall at low volume, but as a spray contractor, sprayed much shorter trees at high volume, with both sets of trees receiving similar amounts of total Cu. Several high-volume spray users indicated that they determined appropriate spray volumes by visual assessment of penetration and coverage of grove blocks while machines were spraying.

GROUND SPEED, NOZZLES, AND PRESSURE. Spray volume is determined

by ground speed, nozzles (disc and core sizes), number of nozzles and pump pressure. Fifty percent of interviewees changed spray volume by adjusting both nozzle output (size and number) and ground speed, 25% percent adjusted only nozzles, 15% adjusted only speed, while 5% adjusted pressure, speed, and nozzling. Of the 36 respondents who reported sprayer pressure values, 92% used pressures between 120 to 200 lb/inch² [psi (830 to 1400 kPa)]. Only one grower used pressure greater than 200 psi [at 230 psi (1600 kPa)] and two used 100 psi (690 kPa). Growers using Curtec machines use the integrated computer to adjust volume or shut off groups of nozzles.

The range of ground speeds used for spraying fresh grapefruit was quite limited. All mid- and high-volume fungicidal applications to fresh grapefruit were reported at 1 to 2 miles/h (mph) (1.6 to 3.2 km·h⁻¹), except one small acreage grower who uses 0.75 mph (1.2 km·h⁻¹). With the Curtec sprayers all applications were made at 3 to 3.5 mph (4.8 to 5.6 km·h⁻¹). For nutritional sprays and sulfur applications, where good coverage is considered less important, speeds were often greater than 2 mph (3.2 km·h⁻¹) even with high-volume sprayers.

The methods by which growers nozzle airblast sprayers was varied but within a limited range (nozzles are not adjusted on Curtec sprayers). Differences within a spray-volume class were as great as differences between spray-volume classes (Table 4). Number of nozzles and disc diameter can vary two to three fold within a volume class. Configuration of nozzles depends on the grower's priority. For example, some growers prefer a fog to achieve their ideal spray, requiring small diameter discs. Other growers prefer larger nozzles for better coverage of tall trees. Plugging problems with smaller nozzles constrains minimum nozzle

size, with few growers using discs smaller than a TeeJet #4 (Spraying Systems Co., Wheaton, Ill.). Thirty-two percent of growers using airblast sprayers maintain uniform disc and core sizes across the entire sprayer manifold for each specified volume, which is the current University of Florida recommendation (Salyani, 2001). However, most growers vary nozzle output across the manifolds on their machines, using from two to four disc sizes and from one to three core sizes for each sprayer setup. All growers who mix nozzles use greatest output from the upper manifold positions, because they feel that larger droplets and more spray volume directed at tree tops improves coverage on tall trees. However, none of the growers indicated adherence to the older recommendation of directing two-thirds of the spray at the top half of the tree (Cromwell, 1975) which is no longer recommended (Salyani, 2001). Most growers said they made an effort to fit the nozzle constellation to the foliage distribution in the tree. This included routinely shutting off nozzles for shorter trees, and because Indian River citrus groves are often planted with two rows per bed, adjusting nozzle output for spraying bed tops versus furrows. Some larger operations designated different sprayers for the bed tops and the water furrows to minimize nozzle adjustment needs. Growers reported adjusting sprayers differently between bed tops and water furrows on 85% of acreage.

Since there were so many combinations of nozzle number, disc size, core selection, ground speed and pump pressures used by the growers, it was not possible to discern much of a relationship with spray-volume categories. There was a 25% decrease in the number of nozzles from high to middle and low volumes and there was a drop in the range of disc and core sizes between mid- and low-volume sprays.

CALIBRATION. Like other practices assessed in this survey, calibration methods varied widely. There were three primary approaches used. For Curtec machines, respondents indicated that calibration was achieved simply by entering designated values into the associated computer (14% of acreage). Otherwise, growers were evenly divided between measuring ground speed and adjusting delivered gallons per minute to achieve desired gallons per acre (44% of acreage) or assessing the time required to empty the sprayer over a known acreage (42% of acreage). Concerning frequency of calibration: respondents representing 33% of acreage reported daily assessment and adjustment of calibration as needed; calibration was reported to be adjusted for every block on 27% of acreage (this includes all Curtec users); and on 38% of acreage it was reported that a more formal calibration was conducted two to five times per year. The remaining 2% of acreage reported calibration from twice per week to every 2 weeks. Many growers record number of tanks applied per block and adjust calibration when either too few or too many tanks are sprayed.

SPRAYING ROW ENDS AND SHUTTING OFF ON DEAD OR MISSING TREES. Methods of spraying trees at the ends of rows is important in Indian River groves, because groves are surrounded by ditches, with exposed surface water often 20 ft or less from row ends. Most growers want to get good tree coverage using practices that minimize pollution with spray materials. The first option is to spray to the end of the row and leave the inside nozzles on as the turn is made (8.2% of the sample acreage used this method). On 29.6% of the reported acreage, sprays are continued until the end of the row and both sprayer sides are shut off on the turn. On 55% of reported acreage, growers sprayed to the trunk on the last tree and then single side wiped the ends, by making an additional pass and spraying perpendicular to the rows along the row ends. On 7% of the acreage, growers varied their practices based on turning radius and distance to ditches in each block. A substantial acreage (20%) received spray to the end of the row and then a followup wipe perpendicular to the rows. The practice of spraying to the trunk and wiping row ends has been promoted

by University of Florida extension for about 2 years and the high level of adoption indicates the rapidity of BMP adoption.

Indian River citrus trees historically have displayed loss rates of 3.5% per year (Muraro et al., 1999), but loss rates have recently accelerated because of citrus tristeza virus (Brown and Spreen, 2000), root weevils (*Diaprepes abbreviatus*), and poor matching of rootstock to soil type (Stover and Castle, 2001). As a result, missing and dead trees are very common in Indian River groves. Shutting off sprayers on dead and missing trees was the routine practice for 82.8% of the acreage represented in this survey. However, on 37.3% of acreage this practice was only engaged for two or more adjacent trees, because growers have either experienced or suspected poor coverage on the next healthy tree when single-tree shut-off is used.

PRECISION TECHNOLOGY. Precision technology, which results in spray application only where there is tree canopy present, could provide more efficient spraying of groves with missing or irregular trees (Balsari et al., 2001). This approach uses sensor-actuated spray manifold control systems so that no spray is applied in gaps within the tree row, and only lower nozzles emit spray where there are shorter trees. From the survey, 14.7% of the acreage was sprayed using this technology, and practitioners felt that resultant savings easily compensated for equipment costs and additional maintenance. Growers representing 21% of the survey acreage have tried such systems, some as long ago as 10 years, but abandoned their use because of equipment problems. However, even this latter group expressed an interest in adopting precision spray technology if it becomes more reliable. Growers with small acreage indicated that cumulative savings would not be sufficient to compensate for equipment expense.

NIGHT APPLICATION. Wind speeds are typically much lower at night in the Indian River area (Stover, unpublished) and night spraying has been proposed as a way of reducing spray drift. Fifteen percent of the grapefruit acreage represented in our survey was sprayed at night. This acreage was being sprayed at 250 gal/acre (2300 L·ha⁻¹) or less, and all practitioners felt that use of smaller droplet size made avoiding high

wind important for both drift reduction and good spray coverage. However, some growers using very low-volume sprays (25 to 35 gal/acre) sprayed during the day. Several growers reported that they tried spraying at night, but considered the potential for accidents too great or felt that additional expenses were unwarranted for nighttime shift management personnel. The growers most committed to night sprayers were those with large acreage who employed dedicated night spray crews, small growers with only one spray machine, and some of the contract sprayers. Of surveyed acreage, 7.6% was sprayed at night using sensor/spray manifold control technology, and almost all of these acres were sprayed with Curtec machines.

ENVIRONMENTAL CONDITIONS THAT PRECLUDE SPRAYING. Growers reported no defined protocol for ceasing spray operations as environmental conditions become unfavorable. They indicated that they would terminate spraying with threat of imminent rain, or when wind visibly prevented good deposition. Some growers noted that they sometimes moved spray operations to mature groves with larger trees in high wind conditions, because the high canopy density in such plantings reduces wind speed and appears to permit good spray coverage. Wind speed measurement was not used as a component of spray management by any interview participants.

Conclusions

Diversity within the industry was apparent for all aspects of foliar spray application. This diversity is a result of numerous factors, including output characteristics of different sprayers and perceived differences in spray requirements for larger trees. However, the most important issues may be the ongoing evolution in spray technology and the milieu in which this evolution occurs. Standard spraying was at very high volumes (2000 gal/acre) 25 years ago (Cromwell, 1975) and many current growers developed their conceptions of fruit production during that period. Although financial concerns encourage experimentation for greater efficiency, and new technology has been developed, people vary in their rapidity and degree of acceptance of new technologies (Rogers, 1983). Much of this may be due to individual risk tolerance, but it is also apparent

that many growers have had negative experiences when using newer practices such as lower spray volumes and precision spraying.

Research and extension literature on citrus spraying correctly focuses on the complexity of predicting effects of spray practices on distribution of materials within trees, even in controlled experiments (Hislop, 1987; Hoffman and Salyani, 1996; Whitney and Salyani, 1991). Consequently, recommendations from authorities often provide limited guidance to growers. This forces the industry to explore spraying as an art, in which changes are attempted on an *ad hoc* basis and either rejected or continued based on individual experience or reports from peers. The tremendous range of grower spray practices appears to reflect the current status of this ongoing, largely independent, experimentation by individual growers.

With this assessment of current spray practices, we can more clearly see the extension and research efforts needed to help growers efficiently and effectively apply foliar materials to citrus trees. It appears likely that many failures reported when growers shifted from established spray practices resulted from use when environmental conditions were adverse to lower volume sprays (Stover et al, 2002b). While traditional high-volume spraying may provide acceptable results across wide environmental conditions and grove characteristics, there are considerable disadvantages to this approach. No single spray practice will be ideal for all situations (Steiner, 1977) and extension recommendations must do a better job of clarifying the limitations and advantages for each spray option. In addition, these survey results provide valuable information for the current effort to formulate and implement surface water protection BMPs for the Indian River area.

In subsequent reports, the information collected in this survey is assessed within the context of current literature on the spray application process (Stover et al., 2002), and will be used to identify opportunities for greater efficiency and efficacy, improved efficiency/efficacy balance, and reduced potential for environmental contamination in a future publication.

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