Pesticide Spray Reduction from Using a Sensor-actuated Spray System in Indian River Grapefruit

Ed Stover, James Salvatore, and Ferdinand Wirth

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SUMMARY. Sensor-actuated precision spray systems are designed to prevent pesticide delivery unless canopy is detected in the corresponding spray zone. Where frequent gaps are present in the tree row, using orchard sprayers with these systems is likely to lower pesticide costs and reduce off-target deposition. Pesticide savings from use of a sensor-actuated precision spray system were assessed in 27 grapefruit (*Citrus paradisi*) blocks selected without prior knowledge of grove characteristics, with nine blocks in each of three age categories: 5-6 years, 10 to 12 years and 20 years and older. The sprayer was optimized for each block by opening only those nozzles appropriate for tree size and furrow depth, so that no spray was delivered under or over the canopy of most trees. The same randomly selected 3.0 to 4.7 acre (1.2 to 1.9 ha) section was then sprayed in each block both with and without activation of the precision spray system. In each block, the precision spray system computer also calculated spray savings based on precision sprayer use with no operator nozzle adjustment. Mean savings in spray material from use of the precision sprayer was 6.6% of total conventional output when comparisons were made with optimal sprayer nozzling in each grove versus 18.6% with no operator adjustment of nozzles. In this study, optimizing nozzling provided a larger proportion of spray savings than use of the precision sprayer on 100% of groves 5 to 12 years old and 44% of groves greater than 20 years old. However, in 70% of groves tested, precision spray systems increased spray savings by more than 2% even when using optimal nozzling. Assignment of precision sprayers to groves with greatest potential for savings will likely provide greatest efficiency, while uniform groves forming hedgerow will offer so little potential savings that even the additional cost of weed management will probably not be recovered.

University of Florida, Indian River Research and Education Center, 2199 South Rock Rd., Ft. Pierce, FL 34945-3138.

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[1]To whom correspondence should be addressed; e-mail ewstover@mail.ifas.ufl.edu.

Sensor-actuated precision spray systems for orchard sprayers have been available since 1984 (Hunt, 2002). Grower perception of unreliability and high maintenance have prevented widespread use (Stover et al., 2002), but substantial improvements are claimed by manufacturers of these products and grower interest has increased. Several companies offer sensor-actuated precision spray systems which can be purchased as an integral component of a sprayer or retrofitted into almost any type of sprayer (Hunt, 2002).

Manufacturers indicate that use of these devices provides 10% to 70% potential overall savings on pesticide use, depending on the grove conditions, and indicate that 25% to 30% is a conservative average (Durand-Wayland, 2002; Roper Growers Cooperative, advertising) for expected savings. The few published reports on use of orchard sprayers with these sensors also indicate savings of around 25% (Balsari et al., 2002; Koch and Weisser, 2000). Since average spray material cost for fresh market grapefruit in the Indian River area was $250/acre ($620/ha) in 2001 and each sprayer was used to treat an average of 260 acres (105 ha) (Stover et al., 2002), the cost of a typical sensor system ($12,000 to 16,000/unit) could be recouped in a single year if spray savings averaged 20% to 25%.

In addition to decreasing production costs, reducing off-target spray application above tree canopies or into gaps between trees offers the potential of substantially reducing surface water pollution with spray materials (Koch and Weisser, 2000; Stover et al., 2003). The purpose of this experiment was to determine the pesticide savings across a range of Indian River grapefruit groves from use of sensor-actuated precision spray systems and optimizing nozzling.

Materials and methods

A commercial 500-gal (1893-L) Durand-Wayland SuperSpray 500 sprayer (LaGrange, Ga.) with a six ultrasonic sensor SmartSpray system was used for all tests in this report and was powered by a tractor (model 7740; New Holland, Pa.). The sprayer and sensor systems were adjusted by a Durand-Wayland specialist before use, according to their optimization protocol. Power-take-off (PTO) and tractor RPM were measured using a tachometer to ensure the sprayer was operating within specified power requirements. Spray was monitored and controlled by a computer mounted in the tractor cab, which is an integrated component of the SmartSpray system.

The spray system was equipped with three ultrasonic sensors and ten nozzles per side. The top sensor controlled the top three nozzles, the middle sensor controlled the middle four nozzles and the bottom sensor controlled the bottom three nozzles. The system can be adjusted to vary the distance that the spray 1) begins before the target is reached and 2) continues after the target has been passed. This can range from 6 inches (15.2 cm), as used in this study, to as much as 90 inches (229 cm).

All sprays were applied at 2.0 miles/h (3.2 km·h^{-1}) at a rate of 125 gal/acre (1170 L·ha^{-1}) when all twenty nozzles were open. Actual gallons per acre varied with the number of nozzles opened at any given time. Orifice disc number (TeeJet D5, Spraying Systems Co., Wheaton, Ill.) and core number (TeeJet 25) were the same for all trials and all sprayer nozzles. The precise acreage sprayed depended on the particular block, but was identical for comparing sprays with and without precision spraying and ranged from 3.0 to 4.7 acres.

Applications were made to commercial grapefruit groves located near Ft. Pierce, Fla. Groves were selected by using grower-supplied maps which indicated only tree variety and age. These groves were typical of commercial citrus in the Indian River area with land bedded to enhance drainage. All groves in this study had two rows of trees on each bed, making it necessary to conduct spray operations on both

Table 1. Parameters for spray data collected in each grapefruit grove.

Sprayer adjustment	Sensor system status	Data collection
Optimally nozzled for each orchard	Sensor-actuated system not engaged: conventional spray	Actual spray volume was measured
Optimally nozzled for each orchard	Sensor-actuated system engaged: no spray in zones without foliage	Actual spray volume was measured
None: computer assumes all nozzles are open	Sensor-actuated system not engaged: conventional spray	Spray volume calculated by SmartSpray system
None: computer assumes all nozzles are open	Sensor-actuated system engaged: no spray in zones without foliage	Spray volume calculated by SmartSpray system

bed tops and through the water furrows at 2 to 5 ft (0.6 to 1.5 m) lower elevation. Grapefruit trees were selected from three age categories: 5 to 6 years, 10 to 12 years, and 20 years and older. Nine blocks in each of the three age classes were selected. Rows selected for spraying were representative of the grove based on tree size, proportion of smaller resets, and proportion of missing trees.

The sprayer setup was optimized for each block by closing top nozzles so that tops of almost all trees were well-covered with spray but few trees were oversprayed, and closing bottom nozzles in deep furrows so that spray did not go below the canopy. Before each run, the sprayer was filled with 500 gal of water. The same block areas were sprayed using the sensor–manifold control system and then resprayed with the system off. After each spray was completed, the sprayer was refilled through a flowmeter (Master Meter, Longview, Tex.) and the volume used was recorded. The integral SmartSpray computer calculated total spray savings from use of the sensor–manifold control system assuming no operator adjustment of nozzles. The spray volume data collected for each grove are indicated in Table 1. These data were used to calculate the percentage of spray saved from use of the sensor/manifold control system compared to conventional spraying, with and without optimizing nozzling.

Numbers of missing trees, average gap between trees, and number and size of replanted trees were determined for each area sprayed. These values were used to calculate predicted savings from use of the precision sprayer. In six groves, savings were well below those predicted. Visual assessment of these groves indicated that in five of the six, weeds likely triggered spray delivery in many areas where there was no tree canopy. In these groves, weeds were manually removed from tree rows and sprays were repeated.

Results and discussion

Savings from precision sprayer with optimal nozzling. With optimal adjustment of nozzles for each grove, use of the SmartSpray system reduced materials sprayed by 6.6% across all groves tested, with mean savings between 4% and 9% for each of the three age classes (Table 2). In individual blocks, savings after optimal nozzle adjustment ranged from 0.5% to 24.6% from use of the precision spray feature. As expected, savings and variability in savings tended to be lowest for trees in the 10- to 12-year age class. Such trees have largely grown to form a hedgerow and have relatively little mortality or resetting, and thus fewer spaces where the sensor-actuated sprayer would shut off.

Factors reducing savings expected with sensor-actuated sprayers. The reduction in spray material observed from use of the sensor-actuated system with an optimally nozzled sprayer can be predicted by three major components: missing trees, smaller replacement trees in the grove, and gaps between trees (after subtracting overspray offset). In 21 of 27 trials, calculations based on these estimates were within 7% of the savings observed from use of an optimally nozzled sprayer. In the remaining cases, failure to achieve predicted savings appeared to result from weeds within the tree rows, which triggered pesticide application, or very deep water furrows that placed beds in range of the lowest sensors, spuriously triggering output from lower nozzles.

In five of the six trials with greatest divergence between predicted and actual spray savings, removal of weeds virtually doubled overall savings (Table 3) and only data following weed removal were included in the overall summary (Table 2). The importance of more stringent weed control and ground cover management is recognized by manufacturers of precision sprayers. The economic benefits of using precision sprayers should include consideration of greater costs for weed control and mowing, which typically account for 21% of grove management expenses in fresh grapefruit production and are estimated at $205/acre ($506/ha) per year (Muraro et al., 2001). Grove managers experiencing poor returns on grapefruit have often adopted minimal grove floor management to reduce production expenses, which is not compatible with use of sensor-actuated sprayers. Greatest economic efficiency is probably achieved by assessing individual groves and using the precision sprayer where expected savings substantially exceed cost of increased groundcover management.

Spurious spray induction in deep water furrows could be resolved by adjusting sensors differently between bedtops and water furrows, so that young replacement trees are sprayed but the bed itself is below sensor detection at all times. Savings realized through this practice will depend on the percentage of time in which sensors would be spuriously triggered and the proportion of overall spray from nozzles controlled by the lowest sensor. In almost all cases, the lower one or two nozzles were shut-off when spraying in the water furrows, because resulting spray would be directed below the canopy. As a result, bed detection by the lower sensor would trigger output from one to two nozzles (versus 6 to 9 total nozzles which were operational), providing 16% to 33% of the full output when passing empty spaces in the water furrow and compromising spray savings by 8% to 16%.

Equipment problems may also substantially reduce savings from use of a sensor-actuated sprayer. In preliminary trials, we found that the sprayer would deliver materials intermittently when passing empty row spaces. This problem was resolved by installing a deep cycle battery dedicated to powering the sen-

Table 2. Spray savings from use of a sensor-actuated precision spray system in nine grapefruit groves of each of three age classes near Ft. Pierce, Fla. Spray savings were determined from 1) actual volume applied with and without SmartSpray system activated, compared using optimal nozzle adjustment on each grove; and 2) SmartSpray system calculations in each grove, which estimate percentage savings achieved versus leaving all nozzles open.

Tree age (years)	1) Spray savings from sensor-actuated system when nozzled for optimal coverage (%)			2) Calculated spray savings from sensor-actuated system with all nozzles open (%)		
	Mean	Lowest	Highest	Mean	Lowest	Highest
All	6.6	0.5	24.6	18.6	2.6	47.2
5–6	8.7	0.7	21.2	28.3	10.4	47.2
10–12	4.2	0.5	10.5	16.3	7.2	28.2
≥20	6.8	0.7	24.6	11.2	2.6	27.0

sor system. Apparently, voltage fluctuations were sufficient to corrupt sensor function even though all of the equipment used was virtually new. In 200 h of operation, the precision system experienced one failure of the onboard computer and three cases in which the hydraulic valves in the sensor-actuated system became clogged. All of these problems were resolved on the following work day. This degree of equipment failure is consistent with reports from growers using sensor-actuated sprayers. Fortunately, problems with the sensor system do not prevent use of the sprayer in standard mode, so time-sensitive sprays can still be applied, however, such disruptions do reduce expected savings in pesticide costs.

SAVINGS FROM PRECISION SPRAYER REPORTED BY INTEGRAL COMPUTER. Not surprisingly, computer calculated savings from using the SmartSpray system were much larger than the measured savings, since default calculations assume no operator shutting-off of nozzles prior to the spray application. Based on this assumption, calculated reduction in spray usage was 18.6% across all blocks (versus 6.6% savings with operator optimization of nozzling). Mean computer calculated savings in 5- to 6-year-old trees was 28.3%, 16.3% in trees 10 to 12 years old, and 11.2% in trees 20 years and older. The overall range of calculated spray reduction spanned from 2.6% to 47.2%.

Actual savings reported by growers are similar to those calculated by the computer in these trials. Apparently, the strict tailoring of sprayer output to individual groves, which was used in this study, is not routine in most commercial operations. However, most Indian River citrus growers did report shutting-off top nozzles in orchards with shorter trees and adjusting nozzling between bed tops and furrows (Stover et al., 2002). Some growers report an unwillingness to leave unsprayed the occasional canopy area of the tallest trees, and therefore slightly overspray much of their grove area. They reason that buildup of disease and insects at the tops of taller trees may compromise pest control throughout the grove, and negate modest savings from more strictly limiting spray height. We know of no studies in which this idea has been tested. Certainly, most important fungal diseases of fresh Florida citrus are greater in areas of prolonged wetting, and would be expected to be minimal in quickly drying tree tops. However, relatively immobile arthropod pests such as mites could develop high populations in unsprayed tree tops.

BENEFITS OF OPTIMIZING SPRAYER NOZZLING AND ACTIVE SPRAY-OPERATOR INVOLVEMENT. Lack of confidence that spray operators will carefully make adjustments and/or belief that too much time is needed may be the primary factors which limit sprayer optimization in commercial groves. However, in these trials, optimal nozzling without use of the sensor-actuated spray feature frequently provided more savings than the additional savings from use of the sensor system. Overall, optimizing nozzling (versus leaving all nozzles open) provided greater spray savings than additional use of the precision sprayer on 100% of groves 5 to 12 years old and 44% of groves more than 20 years old (data not shown). While not tested in these trials, it is clear that use of sensor-actuated spray systems does not eliminate the advantages of having a careful operator adjust nozzling in each block. It was judged that all nozzles should be open for optimal nozzling in both beds and furrows in only 2 of the 27 groves tested. Therefore underspraying and/or overspraying of trees would occur routinely if sensor-actuated sprayers were used without adjusting nozzling. This suggests that most commercial citrus producers would benefit from training spray operators in sprayer optimization. It should be noted that sensor-actuated systems with more sensors and fewer nozzles per sensor are available, and would reduce the degree of overspraying with less benefit from operator adjustment.

Many Florida citrus groves contain dead trees which would trigger release of spray materials from a sensor-actuated system. Sixteen percent of the tree spaces were occupied by dead trees in one of the groves included in this study (data not shown). An alert and properly trained spray operator can shut-off the spray manifold to avoid application to dead trees. In these trials, the spray operator shut-off the spray manifold

Table 3. Effect of weed removal on savings from use of precision sprayer. Data are presented on the four grapefruit groves near Ft. Pierce, Fla., with heaviest weed infestation of 27 groves included in the study. Pesticide savings are those measured after activating the precision spray system on a sprayer nozzled for optimum coverage.

Grove	Grove age (years)	Pesticide savings with optimally nozzled sprayer: Before weed removal	After weed removal
1	5	14.1	20.7
2	5	15.0	21.2
3	5	4.8	17.7
4	≥20	15.3	24.6
5	≥20	3.1	11.2
Mean		10.4	19.1

when two or more adjacent trees were missing or dead, which is the standard practice in the Indian River area (Stover et al., 2002).

Smaller citrus growers report that precision spray equipment is not cost-effective when relatively few acres are managed each year per sprayer (Stover et al., 2002). These trials suggest that a majority of the projected benefits from precision spraying can be realized by careful adjustment of the sprayer for individual groves. However, in 70% of groves tested, precision spray systems increased spray savings by more than 2% even when using optimal nozzling.

Environmental benefits expected. No analysis of drift or other off-target deposition was included in this study. However, research conducted in Germany indicated a drift reduction of about 50% from use of precision sprayers in apple and cherry orchards (Koch and Weisser, 2000). Drift reduction was almost twice as great as pesticide savings. This results from reducing the proportion of spray projected over the canopy, which is likely to be the primary component of drift exiting the sprayed area.

Economics. The cost of a typical sensor system ($12,000 to 16,000 per unit) could be recouped in 1 to 1.33 years with spray savings averaging 18.6%, based on spray material cost for fresh market grapefruit of $250/acre in 2001 and coverage per sprayer of 260 acres/year (Stover et al., 2002). At the more modest savings of 6.6% for optimally nozzled sprayers, savings in spray materials would cover the purchase price of the sensor-control system in 3 to 4 years. Sensor-control units will also have additional maintenance and repair costs, but are likely to be offset by the reduced refill time resulting from use of the precision spray system: by reducing overall spray used by 6.6%, one of every 15 sprayer fillings can be eliminated, substantially reducing cost of the spray procedure as well as spray material. Groundcover maintenance in some groves will need to be increased for effective use of precision sprayers, but these costs were not estimated because of wide variability in current grove maintenance.

Few commercial citrus producers are likely to quickly outfit all sprayers with sensor-actuated spray control systems, therefore, greatest efficiency can be realized by scheduling use of precision sprayers on blocks where the benefit would be greatest. Considering the blocks sprayed in this trial, with optimally adjusted sprayers, the nine blocks with greatest savings from use of the precision system averaged 14% spray reduction, while the nine blocks with the least savings averaged only 1% spray reduction. At 1% savings, sensor system expenses and maintenance or any increased costs of weed control are unlikely to be recovered.

Conclusion

Use of a sensor-actuated spray system significantly reduced mean pesticide usage in a diverse group of Indian River grapefruit groves. Even when using the precision sprayer, there was a marked benefit from careful adjustment of sprayer nozzling based on grove characteristics, and a substantial proportion of spray savings could be realized from sprayer nozzle optimization alone. Nonetheless, use of the precision sprayer feature contributed to spray savings and would likely provide a good return on sensor-system investment in many groves. To realize the potential savings, growers must maintain good ground cover management and encourage operators to monitor proper functioning of the precision spray system including adjustment of lower sensor orientation between bed tops and furrows.

Savings from use of the precision sprayer can be predicted with reasonable accuracy based on missing trees, smaller replacement trees in the grove, and gaps between trees. Assignment of precision sprayers to groves with greatest potential for savings will likely provide greatest efficiency, while uniform groves forming hedgerows will offer so little potential for savings that investment in precision spray-systems will probably not be recovered.

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