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Sensor-Controlled Spray Systems for Florida Citrus[1]

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Introduction

Sensor-controlled precision spray systems are designed to tailor pesticide delivery to individual tree canopies. When used with foliar application equipment, sensors trigger opening of valves so that pesticide is sprayed only in the zones where foliage is present (Figure 1). The same sensor systems can be used with herbicide or fertilizer applicators, but for these uses, application is triggered by the absence of foliage above a specified height, tailoring applications for better reset management. Precision spray systems can greatly decrease the quantity of spray materials used without compromising effectiveness, and can reduce the potential pollution arising from off-target deposition, but must be used properly to achieve these benefits.

Sensor-controlled precision spray systems for orchard sprayers have been available since 1984 (Hunt, 2002). Many citrus growers have tried these devices but reports of unreliability and high maintenance have prevented widespread use (Stover et al., 2002a). However, recent improvements claimed by spray system manufacturers are largely supported by grower reports. The purpose of this

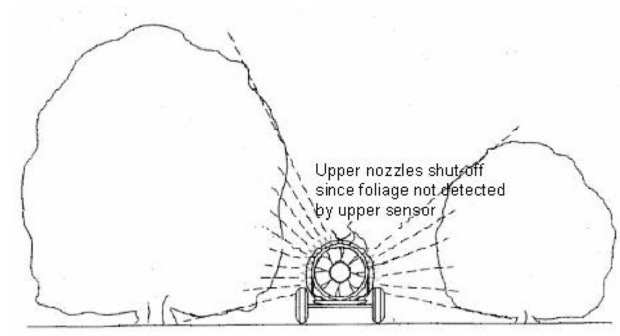

Figure 1. Sprayer with sensor-control system only releases spray when tree canopy is detected within associated zone.

document is to provide information on precision spray equipment to the Florida citrus industry.

Characteristics of Sensor-Controlled Spray Systems

There are currently two basic types of systems available, those using ultrasonic devices and those that use lasers. All systems include an onboard computer (Figure 2) that can be used to program basic sprayer functions and monitors savings from use of the sensor-controlled system. Since the most common use of these systems is for foliar application to the citrus crop, that use will be assumed in the

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following discussion unless other uses are specified. The major systems currently used in Florida are described below, but other systems may be in limited use or may become available.

Figure 2. On-board computer controller for Durand-Wayland integral SmartSpray ultrasonic sensor-control system.

Ultrasonic Systems

How They Work

The Roper Tree-See™ and Durand Wayland SmartSpray™ devices use ultrasonic waves which are reflected by plants (and other surfaces). Sensors and ultrasonic emitters are mounted on both sides of the sprayers front end. When waves are reflected back to a sensor, the valves controlling corresponding nozzles are opened (using compressed air) to release spray material. The sensors can be adjusted so that the zones of canopy detection are configured for the grove being sprayed and the output of the sprayer, and is described in more detail below. Furthermore, to ensure spraying between trees, these systems are adjusted to turn on some distance before the detected foliage and continue spraying some "offset" distance after the detected foliage is past. Typically an offset value of 6 inches is used on both the leading and trailing edge of trees, but higher offsets can be programmed and may be desirable when a vital spray must be applied but wind is deflecting the spray pattern. However, spraying in high winds is not recommended and spray drift itself may be detected by sensors and trigger unwanted spray release.

Typical Configurations

These sensor systems can be purchased as an integral component of a new sprayer or as an add-on to most sprayer brands. Options range from a single sensor to ten sensors. In over-tree sprayers used in new plantings, only a single sensor may be needed to direct the sprayer to shut off between trees. A few growers are using single sensor systems for improving reset management. With these systems, fertilizer and herbicide rigs are configured to turn on at small trees (below sensor detection) to increase herbicide application or selectively fertilize resets (Figure 3).

Figure 3. Tree-See system mounted on herbicide rig to increase application around smaller resets.

Common configurations for foliar spray applicators (e.g. airblast or Curtec™ machines) have 3 or 5 sensors per side. The manufacturers commonly recommend 3 sensors per side for most sprayers and 5 sensors per side for tower sprayers. Ultrasonic sensor systems can be used on most sprayer models, and are suitable for standard "high volume" airblast sprayers and those designed for low volume application such as Curtec™ machines. A Durand Wayland Smart Spray System is shown in Figures 4 and 5.

Sensor/Nozzle Relationships

Each sensor is set up to control specified nozzles. With most sprayers, each sensor controls several nozzles as a single unit. For example, with ten

Figure 4. Durand-Wayland SuperSpray 500 with integral SmartSpray ultrasonic sensor-control system.

Figure 5. Ultrasonic sensors on Durand-Wayland SuperSpray 500.

nozzles and three sensors per side, the system would normally have the upper and lower sensor controlling the three highest and three lowest nozzles respectively, while the middle sensor controls the four middle nozzles. Fewer nozzles per sensor would theoretically provide greater savings by tailoring the spray more precisely to the tree, but no study has been conducted to quantify savings, and manufacturers typically suggest that six sensors provide most of the benefit for less investment. It is possible to alter the nozzles controlled by each sensor on a block by block basis, but this is too time-consuming and complicated to be practical.

Laser Systems

The Chemical Containers Banner Eye™ system is functionally similar to the ultrasonic systems with 3-4 sensors per side, but uses individual lasers and sensors at each position, and an oil-charged system to open and close valves. This system can be installed on most sprayers and is suitable for both high and low-volume spraying.

The AgTec™ Treesense™ system uses a laser-based image range sensor that is mounted on the front of the sprayer and relays tree height, width, and position information into a computer. Electronic solenoid valves are triggered to release spray from an array of nozzles conforming to the tree size, beginning just before the tree is reached and continuing until shortly after the tree is passed. The spray controller can independently operate up to 8 solenoids controlling spray release, providing the equivalent of 4 zones on each side of the sprayer. Currently most Treesense™ systems are purchased as integral systems on AgTec™ sprayers, but they can also be retrofitted onto existing AgTec™ sprayers. A few of these sensor units have also been installed on other low-volume sprayers, but the electronic solenoids arent easily adapted for use in high volume spray systems because of their higher operating pressure. The AgTec™ system is shown in Figure 6.

Figure 6. Laser-based Treesense control system mounted on front of AgTec sprayer.

Potential Savings

Citrus growers, published studies, and equipment manufacturers all report average savings of about 25% when precision sprayers are used for foliar applications. Actual savings will depend on grove characteristics and sprayer setup.

Effect of Grove Characteristics

Gaps in Grove Canopy

In uniform groves with little space between adjoining trees, the use of a sensor-controlled system will provide little additional savings if the sprayer nozzling is properly adjusted for each grove. However, substantial savings should be realized in younger groves in which there are large gaps between trees or in any grove with numerous resets, irregular tree height, and/or missing trees. Savings from use of sensor-control spraying systems can be predicted with reasonable accuracy by the percentage of hedgerow foliage missing because of lost trees, smaller replacement trees in the grove, and gaps between trees. However, savings from gaps between trees will be reduced by the amount of “offset" used to ensure spraying between trees. Output from a precision sprayer will continue unless the gap between trees exceeds twice the offset distance. Since a reasonable minimum “offset” is 6 inches, there must be more than a foot between trees to achieve savings.

Grove Groundcovers

Groundcovers must be carefully managed to achieve potential savings when using a precision sprayer. Sensors do not distinguish between citrus and other objects, so tall grass or weeds will trigger spray delivery. Groundcovers should be mowed shortly before use of a precision sprayer to avoid continuous application from the lowest spray nozzles.

Actual Savings in an Indian River Grapefruit Study

In an Indian River grapefruit study, savings of 19% across 27 diverse blocks from use of the SmartSpray™ system vs. spraying with no operator adjustment of nozzles based on tree or furrow size (Table 1). Savings from use of the precision sprayer dropped to 7% when comparisons were made with the sprayer optimally adjusted for each grove (where many trees would be oversprayed, the top nozzles were closed so that the tops of almost all the trees were well-covered with the spray but few trees were oversprayed, and the bottom nozzles were closed in deep furrows where the spray would be directed below the canopy), and savings in individual blocks ranged from 0.5% to 24.6%. The greatest opportunity for savings in young trees occurs as the sprayer shuts off in gaps between trees that haven't yet grown to form a hedgerow. For mature trees, savings in spray material results primarily from nozzle shut-off at smaller replacement trees and in spaces where dead trees have been removed. As expected, savings tended to be lowest for blocks of mature trees which have grown together to form hedgerows and have relatively little tree-loss or resetting, and thus fewer spaces where the sensor-controlled sprayer would shut-off.

In 48% of all blocks savings were greater than 5% from precision sprayer use when comparisons were made using an optimally nozzled sprayer, while 89% of blocks exceeded 5% spray savings from use of the precision sprayer with no shutting of nozzles based on tree or furrow height.

Optimizing Sprayer Set-up

Benefits

Before spraying a grove, it is recommended that the sprayer be adjusted for tree size by closing the top nozzles so that the tops of almost all trees are well-covered with spray but few trees are oversprayed, and by closing the bottom nozzles in deep furrows so that the spray is not directed below the canopy. This process of “optimizing nozzling” provided almost as much savings as the use of the sensor-controlled spray system in a study on Indian River grapefruit groves. However, in 70% of groves tested, the addition of a precision spray system to an optimally nozzled sprayer increased spray savings by more than 2%.

Disadvantages

Savings reported by Indian River growers using precision sprayers suggest that strict adjusting of sprayer output to individual groves is not routine in most commercial operations. Some growers report an unwillingness to leave the tops of the tallest trees unsprayed, 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. We know of no studies in which this idea has been tested. Certainly, most important fungal diseases of fresh Florida citrus are worst in areas of prolonged wetting, and would be expected to be minimal in tree tops since they tend to dry quickly. However, it is possible that relatively immobile arthropod pests such as mites could develop high populations in unsprayed tree tops. This potential problem could be greatly reduced with an annual topping program.

Benefits of Active Spray-Operator Involvement

Growers' lack of confidence that spray operators will carefully make adjustments and/or the belief that too much time is needed, may limit routine sprayer optimization in commercial groves. However, the use of sensor-controlled spray systems does not eliminate the advantages of having a careful operator adjust the nozzling in each block. In the grapefruit trial, all the nozzles should have been open 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-controlled sprayers were used without adjusting the nozzling. This suggests that many commercial citrus producers would benefit from training spray operators in sprayer optimization. It should be noted that sensor-controlled systems with more sensors and fewer nozzles per sensor are available, and would reduce the degree of overspraying with less need for operator adjustment.

Many Florida citrus groves contain dead trees which would trigger the release of spray materials from a sensor-controlled system. Sixteen percent of the tree spaces were occupied by dead trees in one of the groves in our grapefruit study. 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 when two or more adjacent trees were missing or dead, which is the standard practice in the Indian River area (Stover et al., 2002a), producing additional savings beyond those provided by the sensor-controlled spray system.

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., 2002a). For these growers, 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.

Reduction in Off-Target Spray Deposition

In addition to decreasing production costs, reducing spray application above tree canopies or into gaps between trees offers the potential of substantially reducing pollution of surface water with spray materials (Stover et al., 2002b). 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 from the sprayed area.

Factors Reducing Savings with Sensor-Controlled Sprayers

Several factors can compromise savings expected from the use of a precision spray system. In 21 of 27 trials on Indian River grapefruit, calculations based on missing trees, resets, and gaps, were within 7% of the actual savings observed. In the remaining cases, failure to achieve predicted savings appeared to result from weeds within the tree rows which triggered pesticide application or from very deep water furrows where the lowest sensors were triggered by the bed soil.

Groundcover Management

In five of the six trials with greatest difference between predicted and actual spray savings, removal of weeds virtually doubled overall savings (Table 2) and only data following weed removal were included in the overall summary (Table 1). 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 per acre per year (Muraro et al., 2001). Grove managers experiencing poor returns have often adopted minimal grove floor management to reduce production expenses, which is not compatible with the use of sensor-controlled 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.

Sensor Adjustment

Spray induction in deep water furrows can 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 inappropriately triggered by beds and on the proportion of overall spray from nozzles controlled by the lowest sensor. In the study of sensor-controlled spraying of grapefruit, the lower 1-2 nozzles were shut-off by the operator when spraying in the water furrows of most groves, since spray from these nozzles would be directed below the canopy. Without this adjustment, triggering of the lower sensor by the bed would provide 16-33% of the full output when passing empty spaces in the water furrow and increasing spray use by 8-16% overall.

Equipment Problems

Equipment problems may also reduce savings from the use of a sensor-controlled 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 sensor system. Apparently, voltage fluctuations were sufficient to corrupt sensor function even though all of the equipment used was virtually new. In 200 hours of operation in our study, the Durand Wayland SmartSpray™ system experienced one failure of the onboard computer and three cases in which the hydraulic valves in the sensor-controlled system became clogged. All of these problems could be resolved on the following workday. This degree of equipment failure is consistent with reports from growers using sensor-controlled sprayers. Fortunately, the 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.

Economics

Fresh Grapefruit

Since average spray material cost for fresh market grapefruit in the Indian River area was $250 per acre in 2001, and each sprayer was used for complete yearly spraying on an average of 260 acres of grove (Stover et al., 2002a), the cost of a typical sensor system ($12,000-16,000 per unit) could be recovered in a single year if spray savings averaged the 20-25% indicated by manufacturers and most grower-users. The cost of a typical sensor system could be recovered in 1-1.3 years with the 18.6% savings observed in the IR grapefruit study with no operator adjustment of nozzles. At the more modest savings of 6.6% from using a sensor system on an optimally nozzled sprayer, savings in spray materials would cover the purchase price of the sensor-control system in 3-4 years. Where possible, increasing acreage covered per sprayer will provide a more rapid return on sensor-controlled systems. These units will also have additional maintenance and repair costs, but these 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 the cost of the spray procedure as well as spray material.

Processing Oranges

In groves where fruit is grown for juice, cost of spray materials per acre per year are much less ($130 per acre for central Florida in 2001, Muraro and Still, 2001) and more acres will need to be covered with an individual sprayer to justify the investment in a sensor-controlled spray unit. Operations with relatively small acreage may find that savings in spray materials do not justify equipment costs. However, growers with large acreage could receive a good return on their investment through assignment of the precision sprayers to blocks with numerous resets, skips, and / or gaps between trees.

Advantages of Assigning Precision Sprayers to Specific Blocks

Few commercial citrus producers are likely to outfit all sprayers with sensor-controlled spray systems. Therefore, greatest efficiency can be realized by the use of precision sprayers on blocks where the benefit would be greatest, as described previously. Considering the blocks sprayed in the grapefruit trial with optimally adjusted sprayers, the 9 blocks with greatest savings from the use of the precision system averaged 14% spray reduction, while the 9 blocks with the least savings averaged only 1% spray reduction. At 1% savings, even the increased cost of weed control is unlikely to be recovered, let alone sensor system expenses and maintenance.

Summary

Use of sensor-controlled spray systems is likely to reduce mean pesticide usage across all Florida citrus groves. However, even when using the precision sprayer, there is a substantial benefit from careful adjustment of sprayer nozzling based on grove characteristics. 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 the 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. The use of precision sprayers in groves with the greatest potential for savings will likely provide greatest efficiency, while uniform groves forming hedgerows will offer so little potential for savings that even the additional cost of weed management will probably not be recovered.

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Table 1. Spray reduction from use of sensor-controlled precision spray system in Indian River grapefruit.

Tree age (yrs)	Spray savings from sensor-controlled system when nozzled for optimal coverage (%)			Spray savings from sensor-controlled 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

Table 2. Effect of weeds on savings from use of precision sprayer.

		Pesticide savings with optimally nozzled sprayer	
Grove	Age (yrs)	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