Effectiveness of a Low-volume Spray Technology in the Control of Major Strawberry Diseases in Florida

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ABSTRACT

Florida strawberry production is greatly affected by Botrytis and anthracnose fruit rots (BFR and AFR), caused by Botrytis cinerea and Colletotrichum acutatum, respectively. Fungicide applications are the most effective method for control of both diseases. Traditionally, Florida strawberry growers use sprayers mounted with hydraulic nozzles delivering high flow rates. The objective of this study was to compare the standard hydraulic nozzle (SHN) sprayer with the air-assisted rotary atomizer (AARA). The effects of low volumes on the control of BFR and AFR, the reduction of 25% on fungicide rate, and their operational efficiency were evaluated, and an economic analysis was conducted. Two experiments were conducted (in the 2014-2015 and 2015-2016 seasons) where three treatments were compared: two using the AARA at 25 gal/acre, one of these with 75% of the fungicide rate; and one using the SHN at 100 gal/acre. In the first season, yield, AFR control, and BFR control were similar for all three treatments. However, the AARA treatment had a higher yield than the SHN, with the AARA (75% rate) being more productive. The operational capacity in acres per hour of the AARA was 17% higher than the SHN. Labor and fungicide costs were lower in the AARA treatments. Thus, the technology was shown to be a good fit for Florida growers.

INTRODUCTION

Florida’s strawberry production is located in a subtropical region characterized by mild winters. In addition, the El Niño-Southern Oscillation affects Florida’s climate. This combination of events results in wet winter/springs, usually very favorable for fungal disease development (Pavan et al. 2011).

Two major fungal diseases that challenge growers by significantly reducing marketable yield and limiting strawberry production are Botrytis fruit rot and anthracnose fruit rot (BFR and AFR), caused respectively by Botrytis cinerea and Colletotrichum acutatum (Peres 2015; Smith 1998; Sutton 1998). Most commonly, both pathogens are introduced into commercial fields by quiescently infected transplants. Under favorable environmental conditions (prolonged leaf wetness and mild/warm temperatures), these fungi sporulate and are rapidly dispersed throughout the field by wind, rain splash, and handling operations (Braun and Sutton 1987; MacKenzie and Peres 2012a, 2012b). After infecting flowers and fruit, the tissue becomes covered with masses of spores that serve as secondary inoculum initiating the polycyclic phase of both diseases (Howard et al. 1992; Legard et al. 2001; Mertely et al. 2012). Both BFR and AFR are very aggressive diseases, with yield losses of up to 50% and 70% having been reported, respectively (Cordova et al. 2014; Legard et al. 2003).

The use of more tolerant cultivars is an option for BFR and AFR management. However, cultivars that are more tolerant may not fulfill all the agronomic characteristics required for the growing region, such as bloom period, fruit quality, and yield (Legard et al. 2000; Peres et al. 2010; Seijo et al. 2008). Thus, BFR and AFR management relies strongly on fungicide applications. Traditionally, fungicides are applied in a calendar-based program consisting of weekly sprays of multi-site fungicides, such as thiram or captan, in conjunction with bloom applications of more specific products to AFR and/or BFR (MacKenzie et al. 2003; Peres et al. 2010). However, to reduce the number of fungicide applications by using them only when necessary, many Florida growers have been using the Strawberry Advisory System (StAS).

StAS is a web-based disease forecast tool that predicts AFR and BFR epidemics based on leaf wetness duration (LWD) and temperature during the wet period. Data are collected by weather stations distributed throughout Florida to provide local specific recommendations. Models built in the system use these data to calculate the risk of disease outbreaks. Growers that subscribe to the system are provided with SMS and/or email alerts regarding the risk (low, moderate, or high) of AFR and BFR as well with a fungicide recommendation depending on previous treatments (Pavan et al. 2009; Pavan et al. 2011). Ideally, fungicides should be applied within 24 h after a StAS alert. However, this might be challenging in situations of large acreages, limited time during harvest season, and low operational capacity.

Traditionally, fungicides are applied by conventional boom sprayers fitted with hydraulic nozzles. Sprayers are usually calibrated to deliver flow rates of approximately 100 gal/acre at 200 psi of pressure. Such high volumes can be very time consuming to apply and fungicide efficacy can be impaired if delayed (Peres et al. 2010). Thus, an effective spray technology that increases operational efficiency by reducing flow rate and consequently the number of tank refills could prove to be very beneficial to Florida growers. However, the adoption of new technologies needs to be done with caution. Aspects such as on-target spray deposition,
biological efficacy of pesticides, and minimal spray drift must be preserved.

When air-assisted sprayers were created, the main objective was to increase on-target deposition by using a higher spray droplet velocity and altered trajectory. Directing spray droplets at an inclined angle towards vertical targets resulted in enhanced spray penetration and a more homogeneous distribution on the target surface. Consequently, lower spray volumes could be achieved without impairing spray deposition. Indirectly, non-target contamination and spray drift can be reduced (Grinstein et al. 1988; Hislop et al. 1993; Knoche 1994; Pannelet et al. 2000). Droplet deposition on the underside of leaves is higher with the use of air-assisted sprayers compared to hollow-cone hydraulic nozzles (Holownicki et al. 2000). Even though hollow-cone nozzles were designed to increase coverage and penetration, droplets produced by hydraulic nozzles are retained by the upper leaves instead of deeply penetrating the plant canopy (Sayinaci and Bastaban 2011).

A few studies have been conducted on the use of air-assisted rotary atomizer (AARA) sprayers in different pathosystems (Reilly et al. 2004; Sayinaci and Bastaban 2011; Wise et al. 2010). However, there is no information regarding the applicability of this technology on strawberry production. Thus, the objectives of this research were to compare the standard hydraulic nozzles (SHN) and the AARA technologies with regard to (i) BFR and AFR management effectiveness, (ii) spray operation efficiency, and (iii) cost and benefits.

**EFFECTIVENESS OF TWO SPRAY TECHNOLOGIES IN MANAGING AFR AND BFR**

Two field trials were conducted to compare the effectiveness of AARA and SHN in managing AFR and BFR. The first experiment was established during the 2014-2015 (Year 1) strawberry season at the Gulf Coast Research and Education Center, Wimauma, FL. The second trial was performed during the 2015-2016 (Year 2) season on a commercial farm in Floral City, FL. Strawberry transplants of the cultivars Radiance (Year 1) and Sensation (Year 2) were planted in late September into fumigated plastic-mulched raised beds. Plants were overhead irrigated for 10 days to aid in establishment, and then irrigated and fertilized with drip tape according to conventional practices.

During the two seasons, three treatments were compared: two low-volume using an AARA sprayer calibrated to deliver 25 gal/acre at 30 psi; and the growers’ standard SHN sprayer calibrated to 100 gal/acre at 200 psi. Treatments were arranged in a randomized complete block design with four blocks. In Year 1, plots consisted of three adjacent beds, corresponding to the swath of the AARA and the SHN sprayers. In Year 2, the AARA treatment plots consisted of three adjacent beds, whereas the SHN plots consisted of nine, which corresponded to the swath of the equipment used on the commercial farm. Although there was a difference in plot size in Year 2, all the evaluations on both seasons were done on twenty plants in the center of each plot.

All treatments in both years were sprayed with the same fungicides throughout the season following the StAS risk alerts and fungicide recommendations. Captan (Captan 80 WDG, Arysta LifeSciences, Cary, NC) or thiram (Thiram Granulfo, Chemtura Corp., Middlebury, CT) was sprayed after moderate and high-risk alerts for either AFR or BFR if plants were not in bloom. In bloom, after a BFR moderate alert captan + fenhexamid (Captevate, Arysta LifeSciences) was applied, whereas cyprodinil + fludioxonil (Switch 62.5WG, Syngenta Crop Protection, Greensboro, NC) was used when risk of AFR infection was high and plants were flowering, azoxystrobin (Abound 2.08F, Syngenta Crop Protection) was applied. All products were applied at label rate, except one AARA treatment that was applied with 75% of the rate in all applications. This treatment was included to test the feasibility of reduced fungicide rates when applying a more concentrated suspension. Fungicides were applied within 24 h after a StAS alert and a minimum of a 7-day interval between applications was maintained regardless of consecutive alerts. In Year 1, treatments were sprayed 11 times, whereas 16 applications were made in Year 2.

Fruit was harvested twice weekly from 8 December 2014 to 2 April 2015 (Year 1) and from 9 December 2015 to 9 March 2016 (Year 2). The number of marketable fruit and culls, the weight of marketable fruit, and numbers of AFR- and BFR-diseased fruit were determined.

In the Year 1 trial, the absence of AFR incidence in all the treatments, including in adjacent non-treated fields, led us to inoculate with *C. acutatum*. On 26 January and 10 February 2015, 3 liters of a suspension of 10⁵ conidia/ml was sprayed over the plants of every plot. In addition, on 9 March 2015, six AFR diseased fruit were placed in every plot. Overhead sprinkler irrigation was applied for two hours twice a day for three days to create a more conducive environment for disease development. The same inoculation strategies were not repeated in Year 2 because the trial was conducted in a commercial farm.

Statistical analysis was performed in SAS 9.4 (SAS Institute Inc., Cary, NC) as a generalized linear mixed model using PROC GLIMMIX, with treatments as fixed effects and blocks as random variables. Yield and percent disease incidence were the response variables in the analysis. The fixed factor mean separation was done by using the Fisher’s Protected LSD test (α = 0.05). The incidence of BFR and AFR were calculated as the percentage of diseased fruit of the total number (cull + marketable) of fruit harvested during different periods: disease incidence peaks; and four weeks (approximate time from flower to fruit) after a Switch 62.5WG application was made at bloom. Marketable yield was cumulative from all harvests.

Yield, AFR control, and BFR control in the three treatments tested in the first season did not differ among treatments during any of the periods evaluated. In the second year, BFR control was similar among all the treatments for the entire season’s data. However, the two AARA treatments were more effective than the SHN in reducing the disease when evaluated four weeks after Switch 62.5WG application (4 WAS). Although the two AARA treatments increased yield compared to the SHN, the reduced fungicide rate treatment produced a significantly higher yield than the AARA full rate. Anthracnose fruit rot was not present in the second year (Table 1). Yield in the second season was 32 to 58% smaller than in the first season. The main reason was the warm weather that occurred during November and December 2015, which delayed blooming and consequently reduced the yield. Another factor that contributed to lower yield in the second trial was the higher BFR incidence throughout the season.

**OPERATIONAL CAPACITY ANALYSIS**

The AARA (Proptec Rotary Atomizer, Ledebuhr Industries, Williamston, MI) sprayer was mounted with three nozzles spaced 4-ft apart and approximately 3-ft above plant canopy. Each nozzle delivered 1 gal/min at 30 psi of pressure. In both trials, the travel speed was 4.8 mph to achieve a desired flow rate of 25 gal/acre. Each nozzle was located inside a spinning disc cage, which was inclined by 45°. The air flow provided by the fans hit the plant canopy at the same angle. Fans were composed of five blades...
fitting the shaft of the rotating cages. Air speed was approximately 15 mph with a disc rotation of 3500 rpm.

In the SHN treatment, a standard tank towed behind a tractor was used. The sprayer was mounted with six nozzles per sprayed bed in Year 1 and four in Year 2. The sprayer had the swath of three and nine 4-ft-center beds in Year 1 and 2, respectively. Nozzles were TeeJet disc core model D3 DC 45 (Year 1) and Albuza ATR 80 (Year 2), both with a hollow-cone spray pattern. In both experiments, the boom pressure was 200 psi and the travel speed was adjusted to attain a flow rate of 100 gal/acre: 4.0 mph (Year 1) and 4.5 mph (Year 2). Nozzles were directed at the plant canopy in a semi-circle format to achieve good foliage coverage and canopy penetration.

An operational capacity simulation was conducted to compare the equipment’s work rate. The equipment calibration set up was considered in the simulation. Other assumptions were taken into account, such as: sprayed area of 52 acres; sprayer tank capacity of 500 gallons; swath of 12-ft (three beds); and time of mixing and loading pesticides of 25 min. Calculations were done in a spreadsheet and results are presented in Table 2.

The acre per hour spray capacity of the AARA treatments was about 17% higher than the SHN. Moreover, the AARA treatments could spray four times more acres per tank compared to the SHN, with time spent spraying one acre during the whole season. Eleven and sixteen fungicide applications were done in Years 1 and 2, respectively. Equipment depreciation was determined by considering the machinery acquisition price of $30,000 and $25,000 for the SHN and AARA, respectively. Depreciation was calculated over a period of 10 years and was standardized into $/acre considering a 52-acre farm. No salvage value was included. The difference between the income and the costs calculated corresponds to the partial profit of each treatment (Table 3).

The spray labor cost and machinery depreciation were $15/acre and $9.59/acre lower, respectively, in the AARA than in the SHN.

### TABLE 1

#### Yield and disease incidence during different periods of Year 1 and Year 2 experiments.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Season 2014-2015 (Year 1)</th>
<th>Season 2015-2016 (Year 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4 WAS^w</td>
<td>4 WAS^w</td>
</tr>
<tr>
<td>Botrytis fruit rot (%)</td>
<td>4 WAS^w</td>
<td>4 WAS^w</td>
</tr>
<tr>
<td>Anthracnose fruit rot (%)</td>
<td>4 WAS^w</td>
<td>4 WAS^w</td>
</tr>
<tr>
<td>SHN 100 gal/acre^x</td>
<td>4.4</td>
<td>22.6 a^z</td>
</tr>
<tr>
<td>AARA 25 gal/acre^v</td>
<td>7.2</td>
<td>15.7</td>
</tr>
<tr>
<td>AARA 25 gal/acre (75% rate)</td>
<td>1.9</td>
<td>13.1</td>
</tr>
<tr>
<td>Probability of a greater F value^v</td>
<td>0.5544</td>
<td>0.0133</td>
</tr>
<tr>
<td>SHN 100 gal/acre</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>AARA 25 gal/acre</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>AARA 25 gal/acre (75% rate)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Probability of a greater F value^v</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

^x SHN= standard hydraulic nozzle; AARA= air-assisted rotary atomizer.

^w Yield in lb/acre of harvests done during the entire season. Harvests were done from 8 December 2014 to 2 April 2015 (Year 1), and from 9 December 2015 to 9 March 2016 (Year 2).

^z Probability associated with type III test of fixed effects.

^w Incidence of BFR and AFR of harvest made 4 weeks after Switch 62.5WG application. Harvests were done on 12 February 2015 (Year 1), and on 25 February 2016 (Year 2).

^z Incidence of BFR during the entire season. Harvests were done from 8 December 2014 to 2 April 2015 (Year 1), and from 9 December 2015 to 9 March 2016 (Year 2).

### TABLE 2

#### Operational capacity of the three treatments tested during Year 1 and Year 2 experiments.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Speed (mph)</th>
<th>acre/h</th>
<th>acre/tank</th>
<th># refills</th>
<th>Time to refill (h)</th>
<th>h/tank</th>
<th>Total h spray</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHN 100 gal/acre^x</td>
<td>4.0</td>
<td>5.8</td>
<td>5</td>
<td>10.4</td>
<td>4.3</td>
<td>0.8</td>
<td>13.3</td>
</tr>
<tr>
<td>AARA 25 gal/acre</td>
<td>4.8</td>
<td>7.0</td>
<td>20</td>
<td>2.6</td>
<td>1.1</td>
<td>2.9</td>
<td>8.6</td>
</tr>
</tbody>
</table>

^x SHN= standard hydraulic nozzle; AARA= air-assisted rotary atomizer.

Note: The operational capacity was calculated based on the following assumptions: Sprayed area, 52 acres; tank capacity, 500 gal; Swath = 12 feet; timing of mixing and loading = 25 minutes.

### ECONOMIC ANALYSIS

A partial budget analysis was done to evaluate the economic performance of the three treatments conducted in Year 1 and Year 2. Incomes and costs were used to calculate the profit related to each treatment. The income ($/acre) was calculated by adding the product of every harvest yield converted to the number of 8-lb flats/acre and the daily strawberry flat price ($/flat). The local strawberry flat price was taken from the USDA Agricultural Marketing Service database. Prices for Plant City region were used for Year 1, and Floral City for Year 2. Fixed costs such as fertilization, irrigation, planting, among others, were not computed. Only costs that varied across treatments were used in the evaluation (fungicide costs, spray labor, and equipment depreciation).

### TABLE 3

#### Income, costs, and partial profit of each treatment (Table 3).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Income ($)</th>
<th>Costs ($)</th>
<th>Partial profit ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHN 100 gal/acre</td>
<td>32990</td>
<td>29144</td>
<td>0.005</td>
</tr>
<tr>
<td>AARA 25 gal/acre</td>
<td>3978</td>
<td>21476 a</td>
<td>0.0028</td>
</tr>
<tr>
<td>AARA 25 gal/acre (75% rate)</td>
<td>0.1077</td>
<td>0.0614</td>
<td></td>
</tr>
</tbody>
</table>

Note: The partial profit was calculated by subtracting the costs from the income for each treatment.
Fungicide cost only differed in the AARA (75% rate) treatment, where the cost was 25% lower than in the other two. The factor that played a major role in the analysis was the income, which was strongly related to yield. Since there were no significant differences in yield in Year 1, the partial profit does not have a wide range. However, because of the differences in yield in Year 2, both AARA treatments increased the partial profit compared to the SHN. AARA (75% rate) performed best, generating $8,294/acre more than the SHN treatment.

**FINAL CONSIDERATIONS OF A LOW-VOLUME SPRAY TECHNOLOGY FOR DISEASE CONTROL ON STRAWBERRIES**

The use of low-volume spray technologies such as the AARA did not impair the effectiveness of fungicide treatments in managing BFR and AFR affecting Florida strawberries. In fact, the AARA technology provided better BFR control than the SHN when evaluated four weeks after the application of Switch 62.5WG in Year 2. Furthermore, the AARA treatments had significantly higher yields during that experiment, with the AARA (75% rate) being more productive than the AARA full-fungicide rate. The finer droplet size of the AARA compared to the SHN and the assistance of air provides better spray deposition on foliage and flowers, aiding the effectiveness of such treatments. Previous publications had shown that spray volume was often of secondary importance compared to droplet size. Finer rather than coarser and air-assisted rather than unassisted sprays have improved on-target deposition (Hislop et al. 1995; Knoche 1994). Our findings open the possibility for the reduction of fungicide rates when applied in low-volume (more concentrated) mixtures. This has been reported in previous studies conducted in Australia, the UK, and the Netherlands in different pathosystems (Penrose 1995; Wicks and Nitschke 1986). For instance, Wicks and Nitschke (1986) tested the effectiveness of fenamuron and a pre-mixture of etaconazol + captan in managing apple scab caused by *Venturia inaequalis* in Australia. They found that reduction of the flow rate from 85 to 11 gal/acre and reduction of fungicide to 25% of label rate did not jeopardize disease control, supporting our findings.

In combination with the benefits cited above, the low-volume technology (AARA) has the potential to increase the spraying operational capacity and allow for improved timing of fungicide applications. In the simulated farm study, the use of the AARA equipment led to a reduction of 75% in the number of times the equipment needed to be refilled compared to the SHN sprayer. This, in addition to higher ground speed made the AARA approximately 35% more efficient than the SHN in spraying an area of 52 acres. Since fungicide timing is an important factor for best managing BFR and StAS recommends sprays to be done within 24 h after alerts, AARA seems to be a good fit for Florida strawberry growers.

The two factors that support reduced costs by using the AARA are labor and fungicide, regardless of equipment prices. Fungicide costs were 25% lower in the AARA (75% rate) treatment than in the others and as we showed above it did not impair BFR management. Spray labor cost was 35% and 30% lower in the low-volume treatments in Years 1 and 2, respectively, due to the increased work rate of the AARA compared to the SHN treatment in terms of acres sprayed per hour and time spent with fungicide mixing and loading operations. Machinery depreciation costs ($/acre) are dependent on acquisition price, salvage value, and area sprayed per season. Thus, they vary considerably among different situations.

In summary, the advantages of the low-volume (AARA) technology are that large fields can be sprayed more quickly after StAS alerts, and there is a reduction in labor and fungicide costs per acre compared to the SHN technology. Such characteristics make the AARA a good alternative for Florida strawberry growers when large fields need to be sprayed on a tight schedule of harvest and spray operations. However, the acquisition price of both AARA and SHN equipment must be taken into consideration before making decisions because prices may vary by location and manufacturer.

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**LITERATURE CITED**
