Understanding Effective Citrus Spray Application through Computer Simulations

Peter Ako Larbi, Ph.D.
Assistant Cooperative Extension Specialist
Agricultural Application Engineering
Kearney Agricultural Research & Extension Center
Parlier, CA
palari@ucanr.edu

UC Ag Experts Talk
Citrus Spray Training Webinar
August 21, 2019
Program Overview

- Development and deployment of DSSs to assist growers and applicators with spray application decisions.
- Development and application of GIS maps to enable site-specific management of orchards.
- Needs assessment of grower and applicator spray application equipment and practices.
- Organizing and conducting timely and need-based training and technology transfer in pesticide spray application.
- Developing and disseminating science-based information for the clientele.

- Evaluation of orchard spray application effectiveness based on different sprayers and different sprayer configurations.
- Effectiveness and efficiency assessment of commercial equipment, sensor, and control systems for site-specific and precise spray application.
- Developing and deploying real-time sensing and control systems for precise and automated spray application.
- Development and deployment of DSSs to assist growers and applicators with spray application decisions.
- Needs assessment of grower and applicator spray application equipment and practices.
- Organizing and conducting timely and need-based training and technology transfer in pesticide spray application.
- Developing and disseminating science-based information for the clientele.
• Airblast sprayers are the main types of sprayers used for pesticide application.

• Critical need to achieve high on-target deposition and coverage with minimal losses for effective and economical pest and disease control.

• However, significant material loss can result due to drift and ground fallout because of variability in tree canopy profile and size.

• Such losses lead to increased production costs and reduced profits.
Airblast Spray Dispersion

Photo: Conventional airblast sprayer with typical polar jet design. Credit: Peter Ako Larbi

Photo taken 2009 in a citrus plot at University of Florida’s Citrus Research and Education Center in Lake Alfred, Florida. Credit: Peter Ako Larbi
Airblast Spray Essentials

Air-carrier/Air-blast Spraying

Atomization of tank mix liquid → Transport of spray droplets toward trees → Deposition on intercepting canopy → Drift beyond canopy → Ground deposit: directly/indirectly

Airblast Spray Essentials
Dynamics of Airblast Spray Application

Atomization produces spray consisting of a spectrum of droplet sizes.

Spray solution in tank

Factors affecting droplet size:
- physical properties of tank solution
- nozzle design
- operating pressure
Poll Questions

1. Which of the following is true about airblast sprayers?
   a) Airblast sprayers are mainly used to apply herbicides.
   b) Airblast sprayers have limited use in citrus pest control.
   c) Airblast sprayers use a high-volume high-velocity air to transport spray droplets.

2. At any instance during an airblast spray application, which of the following defines the target trees?
   a) The target trees are all the trees in the orchard.
   b) The target trees are the trees adjacent to the sprayer in the immediate tree rows that are directly being sprayed.
   c) The target trees are all the trees that the sprayer has already sprayed.

3. Which of the following is a desired outcome of airblast spray application?
   a) Canopy deposition.
   b) Spray drift.
   c) Ground deposition.
Material Balance in Spray Application

Lower than desired on-target spray deposition persistently occurs in citrus spray application due to several interacting factors:

- equipment design
- application parameters
- spray physical properties
- tree characteristics
- weather condition

Complex interactions influence on-target spray deposition and off-target losses.

(Salyani et al., 2007)
Computer Modeling Motivation

Application Parameters
- Airflow Rate (cfm)
- Nozzle Type
- Upper Nozzles
- Lower Nozzles
- Total No. of Nozzles
- No. of Upper Nozzles
- No. of Lower Nozzles
- Operating Pressure (psi)
- Ground Speed (mph)

Weather Parameters
- Temperature °F
- Relative Humidity (%)
- Wind Speed (mph)

Tree Characteristics
- Tree Height (ft)
- Skirt Height (ft)
- Canopy Diameter (ft)
- Foliage Density

Orchard Condition
- No. of Trees / Row
- No. of Rows
- Tree Spacing (ft)
- Row Spacing (ft)
- No. of Missing Trees

Other Parameters
- Output/Side (gpm)
- Total Volume Applied (gal)
- Total Area Covered (acre)
- Application Rate (gpa)
- No. of Trees Sprayed
Not this model!!!

Not this!!!

Not this!!!
Spray Model

Compartments Characteristics

- Cross-sectional area
- Volume
- Air velocity

University of California
Agriculture and Natural Resources
Research and Extension Center System

AgAppE Lab@KARE Center
Spray Simulation

- Distance from sprayer outlet, ft
- Sprayer air velocity, mph

- Droplet Size, µm
- Operating Pressure, psi

- Nozzle VMD (µm) ASABE Droplet Category
  - D2-13: 148.39 Very Fine to Fine
  - D3-23: 166.33 Fine
  - D4-25: 219.63 Fine to Medium
  - D5-45: 252.32 Fine to Medium
  - D6-46: 330.70 Medium to Coarse

- Percentage of active ingredient in evaporating droplet, %

- Elapsed time, s

- University of California
  Agriculture and Natural Resources
  Research and Extension Center System

- AgAppE Lab@KARE Center
Effect of Weather

Temperature

- 5°C
- 15°C
- 25°C
- 35°C

Airborne spray mass, kg

Distance from airsprayer outlet, m

Rel. Humidity

- 50%
- 66%
- 82%
- 98%

Airborne spray mass, kg

Distance from sprayer outlet, m

Wind Speed

- 0.5 m/s
- 1.7 m/s
- 2.9 m/s
- 4.1 m/s

Airborne spray mass, kg

Distance from sprayer outlet, m

Wind Direction

- 0°
- 30°
- 60°
- 90°

Airborne spray mass, kg

Distance from sprayer outlet, m
4. **Which of the following reasons incorrectly justifies the need for or use of model simulations?**
   a) It is very difficult to guestimate spray application outcome because of complex interactions among influential factors.
   b) Model simulations eliminate the limitations of actual field experiments in terms of time, labor, material, and other resources.
   c) Model simulations can create very cool graphs that cannot be created with actual field experiments.

5. **Which of the following weather conditions should be avoided because of its effect on spray application?**
   a) High relative humidity because it favors spray drift.
   b) Low air temperature because it favors spray drift.
   c) High wind speed because it favors spray drift.
Model Validation

Dispersion Test

- Spray Off
- Spray On

Ground Targets
Sample Locations
Buffer 1
Buffer 2

Note: All dimensions are in meters

Spray Source

0.6
1.8
3.0
1.6
2.6
3.6
4.6
5.6

PVC Pipe Structure
Rears Power Blast Sprayer
Binder Clip
H3 target holder
H3 target
H1 target holder
H1 vertical target
H1 horizontal target

2 Nozzles – Albuz Lilac
- Blue

2 Speeds – Slow = 2.4 km/h
- Fast = 4.8 km/h

Spray liquid consisted of pyranine dye solution and spray analysis was done by fluorometry.

Deposition Test

Spray Off
N
Spray On

2 Nozzles – Albuz Lilac
- Blue

2 Speeds – Slow = 2.4 km/h
- Fast = 4.8 km/h

Spray liquid consisted of pyranine dye solution and spray analysis was done by fluorometry.

Note: All dimensions are in meters

Sample Locations

Buffer 2
Buffer 1

Ground Targets
Sample Locations

University of California
Agriculture and Natural Resources
Research and Extension Center System
Model Validation

Dispersion Test

Modeling Efficiency, EF = 61%; Correlation Coef., r = 0.92

Deposition Test

Modeling Efficiency, EF = 78%; Correlation Coef., r = 0.90
Model-based Expert System

Structure of ES with arrows showing the direction of information flow.

GUI for spray evaluation showing an ongoing simulation.

Simplified flowchart for spray evaluation simulation

6. Validating a model with data from an actual field experiment gives us some confidence to trust the model’s predictions or make decisions based on it. True or false?
   a) True.
   b) False.
### Other Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output/Side (gpm)</td>
<td>0.04587</td>
<td>0.04587</td>
<td>0.04587</td>
</tr>
<tr>
<td>Total Volume Applied (gal)</td>
<td>651</td>
<td>651</td>
<td>651</td>
</tr>
<tr>
<td>Total Area Covered (ac)</td>
<td>11.938</td>
<td>11.938</td>
<td>11.938</td>
</tr>
<tr>
<td>Application Rate (gpa)</td>
<td>55</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>No. of Trees Sprayed</td>
<td>2000</td>
<td>2000</td>
<td>2000</td>
</tr>
</tbody>
</table>

### Airflow Rate (cfm)

- 19,000
- 33,500
- 48,000
Nozzle Size

<table>
<thead>
<tr>
<th>Nozzles</th>
<th>D3-13</th>
<th>D4-23</th>
<th>D5-25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage</td>
<td>Canopy Deposition (%)</td>
<td>Ground Fallout (%)</td>
<td>Spray Drift (%)</td>
</tr>
<tr>
<td>D3-13</td>
<td>57%</td>
<td>9%</td>
<td>34%</td>
</tr>
<tr>
<td>D4-23</td>
<td>61%</td>
<td>10%</td>
<td>29%</td>
</tr>
<tr>
<td>D5-25</td>
<td>60%</td>
<td>19%</td>
<td>21%</td>
</tr>
</tbody>
</table>

Other Parameters

- Output/Side (gpm): 0.02621, 0.04587, 0.1065
- Total Volume Applied (gal): 372, 651, 1510
- Total Area Covered (ac): 11.938, 11.938, 11.938
- Application Rate (gpa): 31, 55, 127
- No. of Trees Sprayed: 2000, 2000, 2000
**Operating Pressure**

- **Operating Pressure (psi)**: 115, 145, 175

---

**Other Parameters**

<table>
<thead>
<tr>
<th></th>
<th>0.0411</th>
<th>0.04587</th>
<th>0.05039</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Output/Side (gpm)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total VolumeApplied (gal)</strong></td>
<td>583</td>
<td>651</td>
<td>715</td>
</tr>
<tr>
<td><strong>Total Area Covered (ac)</strong></td>
<td>11.938</td>
<td>11.938</td>
<td>11.938</td>
</tr>
<tr>
<td><strong>Application Rate (gpa)</strong></td>
<td>49</td>
<td>55</td>
<td>60</td>
</tr>
<tr>
<td><strong>No. of Trees Sprayed</strong></td>
<td>2000</td>
<td>2000</td>
<td>2000</td>
</tr>
</tbody>
</table>

---

**Graph: Operating Pressure (%)**

- **Canopy Deposition (%)**
  - 115 psi: 61%
  - 145 psi: 61%
  - 175 psi: 59%

- **Ground Fallout (%)**
  - 115 psi: 10%
  - 145 psi: 10%
  - 175 psi: 9%

- **Spray Drift (%)**
  - 115 psi: 29%
  - 145 psi: 29%
  - 175 psi: 32%
7. According to model simulation results from preceding slides, which of the following general statements about citrus airblast spray applications is true?
   a) Increasing airflow rate increases percentage canopy deposition.
   b) Increasing nozzle size increases percentage canopy deposition and percentage potential spray drift.
   c) Increasing operating pressure increases percentage canopy deposition.
Ground Speed

<table>
<thead>
<tr>
<th>Ground Speed (mph)</th>
<th>1</th>
<th>2.5</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground Speed (mph)</td>
<td>1</td>
<td>2.5</td>
<td>4</td>
</tr>
</tbody>
</table>

### Other Parameters

<table>
<thead>
<tr>
<th></th>
<th>0.04587</th>
<th>0.04587</th>
<th>0.04587</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output/Side (gpm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Volume Applied (gal)</td>
<td>1627</td>
<td>651</td>
<td>407</td>
</tr>
<tr>
<td>Total Area Covered (ac)</td>
<td>11.938</td>
<td>11.938</td>
<td>11.938</td>
</tr>
<tr>
<td>Application Rate (gpa)</td>
<td>136</td>
<td>55</td>
<td>34</td>
</tr>
<tr>
<td>No. of Trees Sprayed</td>
<td>2000</td>
<td>2000</td>
<td>2000</td>
</tr>
</tbody>
</table>

### Graph

- **Percentage**
  - Canopy Deposition (%)
  - Ground Fallout (%)
  - Spray Drift (%)

- **Ground Speed (mph)**
  - 1 mph: 52% Canopy Deposition, 14% Ground Fallout, 29% Spray Drift
  - 2.5 mph: 34% Canopy Deposition, 10% Ground Fallout, 29% Spray Drift
  - 4 mph: 61% Canopy Deposition, 29% Ground Fallout, 10% Spray Drift
Canopy Foliage Density

Other Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Value 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output/Side (gpm)</td>
<td>0.04587</td>
<td>0.04587</td>
<td>0.04587</td>
</tr>
<tr>
<td>Total Volume Applied (gal)</td>
<td>651</td>
<td>651</td>
<td>651</td>
</tr>
<tr>
<td>Total Area Covered (ac)</td>
<td>11.938</td>
<td>11.938</td>
<td>11.938</td>
</tr>
<tr>
<td>Application Rate (gpa)</td>
<td>55</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>No. of Trees Sprayed</td>
<td>2000</td>
<td>2000</td>
<td>2000</td>
</tr>
</tbody>
</table>

Canopy Deposition (%)

- Low: 45%
- Medium: 61%
- High: 80%

Ground Fallout (%)

- Low: 8%
- Medium: 10%
- High: 11%

Spray Drift (%)

- Low: 9%
- Medium: 29%
- High: 11%
Wind Speed

<table>
<thead>
<tr>
<th>Wind Speed (mph)</th>
<th>2</th>
<th>6.5</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage</td>
<td>66%</td>
<td>61%</td>
<td>52%</td>
</tr>
<tr>
<td>Canopy Deposition (%)</td>
<td>12%</td>
<td>10%</td>
<td>8%</td>
</tr>
<tr>
<td>Ground Fallout (%)</td>
<td>22%</td>
<td>29%</td>
<td>40%</td>
</tr>
<tr>
<td>Spray Drift (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Other Parameters

<table>
<thead>
<tr>
<th></th>
<th>0.04587</th>
<th>0.04587</th>
<th>0.04587</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output/Side (gpm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Volume Applied (gal)</td>
<td>651</td>
<td>651</td>
<td>651</td>
</tr>
<tr>
<td>Total Area Covered (ac)</td>
<td>11.938</td>
<td>11.938</td>
<td>11.938</td>
</tr>
<tr>
<td>Application Rate (gpa)</td>
<td>55</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>No. of Trees Sprayed</td>
<td>2000</td>
<td>2000</td>
<td>2000</td>
</tr>
</tbody>
</table>

Wind Speed (mph) Distribution:
- 2 mph: 12%
- 6.5 mph: 22%
- 11 mph: 8%

Canopy Deposition, Ground Fallout, and Spray Drift percentages are shown for each wind speed category.
According to model simulation results from preceding slides, which of the following general statements about citrus airblast spray applications is true?

a) Increasing sprayer ground speed increases percentage canopy deposition.
b) Increasing canopy foliage density increases percentage potential spray drift.
c) Increasing relative humidity increases percentage potential spray drift.
Analysis of Advanced Airblast Systems

### Systems Tested

<table>
<thead>
<tr>
<th>Trt</th>
<th>System</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Conventional</td>
<td>No variable rate</td>
</tr>
<tr>
<td>2</td>
<td>Automatic nozzle rate adjustment only</td>
<td>Could be based on aerial map</td>
</tr>
<tr>
<td>3</td>
<td>Automatic air assistance control only</td>
<td>Could be based on aerial map</td>
</tr>
<tr>
<td>4</td>
<td>Automatic application rate control only</td>
<td>Based on real-time speed sensing</td>
</tr>
<tr>
<td>5</td>
<td>Automatic nozzle on/off control only</td>
<td>Based on real-time tree canopy sensing</td>
</tr>
</tbody>
</table>

### Systems Setup

- **Orchard & Tree Characteristics**
  - ✓ 20 ft row spacing x 13 ft tree spacing
  - ✓ 100 rows x 100 trees/row = 10,000 trees
  - ✓ 0% missing-tree (0% MT) situation
  - ✓ 3 tree sizes: small = 8 ft high x 6 ft dia
    - medium = 16 ft high x 9.5 ft dia
    - large = 24-ft x 13 ft
  - ✓ 3 foliage densities: low (LD), medium (MD), and high (HD)

- **Weather Conditions**
  - Temp = 77°F, RH = 75%, and wind speed = 5 mph

- **Standard Sprayer Setup**
  - Type: Conventional airblast
  - Air outlet width (horizontal) = 0.4 ft
  - Air outlet length (vertical) = 4.8 ft
  - Nozzle type = D4-23 disc-core
  - # nozzles = 10 /side
Automatic nozzle rate adjustment

Tree height = 8 ft
Canopy dia = 6 ft
Skirt height = 1 ft

Spray: 20 gpa
Air: 38,000 cfm

Automatic air assistance control

Tree height = 16 ft
Canopy dia = 9.5 ft
Skirt height = 1 ft

Spray: 68 gpa
Air: 18,000 cfm

Automatic application rate control

Spray: 68 gpa
Air: 38,000 cfm

Automatic nozzle on/off control

Spray: 16 gpa
Air: 38,000 cfm

Overall, 207 non-replicated simulation runs
Orchard Tree Configuration (%Small-%Medium-%Large)

<table>
<thead>
<tr>
<th>Tree Configuration</th>
<th>Uniform</th>
<th>Non-uniform</th>
</tr>
</thead>
<tbody>
<tr>
<td>100-0-0</td>
<td>50-25-25</td>
<td></td>
</tr>
<tr>
<td>0-100-0</td>
<td>25-50-25</td>
<td></td>
</tr>
<tr>
<td>0-0-100</td>
<td>25-25-50</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Foliage Density</th>
<th>Leaf Area Density (m²/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>3.0</td>
</tr>
<tr>
<td>Medium</td>
<td>3.8</td>
</tr>
<tr>
<td>High</td>
<td>5.4</td>
</tr>
</tbody>
</table>
Data Analysis

- Focused on canopy deposition, ignoring ground fallout and spray drift.

- \( \text{Spray rate} = \frac{\text{volume applied}}{\text{number of trees sprayed}} \)

- \( \text{Deposition rate} = \frac{\text{volume deposited}}{\text{number of trees sprayed}} \)

- \( \text{Spray savings} = \) deficit volume sprayed compared to a corresponding conventional airblast application

- \( \text{Deposition savings} = \) supplementary deposition compared to a corresponding conventional airblast application.

- \( \text{Total savings} = \text{Spray savings} + \text{deposition savings} \)
Automatic Air Assistance Control

Application rate same as conventional application
No spray savings
Automatic Application Rate Control

Application rate maintained at conventional rate
Automatic Nozzle On/off Control

No deposition savings
Total Application Savings

- Total savings, gal/tree
- Tree configuration, small-medium-large
- Auto Nozzle Control
- Auto Air Assistance Control
- Auto Rate Control
- Auto Nozzle on/off

100-0-0  0-100-0  0-0-100  50-25-25  25-50-25  25-25-50

Uniform  Non-uniform

University of California
Agriculture and Natural Resources
Research and Extension Center System
Poll Questions

9. From simulation results in earlier slides, which of the following advanced systems may benefit (in terms of material savings) spraying an orchard having uniform foliage density hedgerows (i.e. tree canopies touching) trimmed at the top and sides?
   a) An airblast sprayer with automatic nozzle flow adjustment, based on foliage density.
   b) An airblast sprayer with automatic application rate control, based on ground speed.
   c) An airblast sprayer with automatic nozzle on/off control, based on presence/absence of tree.

10. In an orchard with variable tree sizes, canopy gaps, and possible missing trees, which of the following advanced systems may provide the greatest benefit in terms of material savings?
    a) An airblast sprayer with automatic nozzle flow adjustment, based on foliage density.
    b) An airblast sprayer with automatic application rate control, based on ground speed.
    c) An airblast sprayer with automatic nozzle on/off control, based on presence/absence of tree.
Take-home Messages

1. Guesstimating the outcome of an airblast spray application (as in canopy deposition, drift, and ground fallout) is almost impossible.

2. Using modeling and simulation tools for predictions can improve decision making for better planning.

3. *CitrusSprayEx* ES or similar tools can help.
References


Thank You!

Peter Ako Larbi, Ph.D.
palarbi@ucanr.edu