Epidemiology of Citrus Diseases

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PLP 5115c
What is Epidemiology?

○ The study of epidemics
  ✓ Change in disease intensity in a host population over time and space
○ Change: often an increase
  ✓ Dynamic process
○ Disease: dealing with the ‘disease’, not just pathogen or crop (plant)
  ✓ Citrus canker rather than Xanthomonas citri subsp. citri
  ✓ Huanglongbing rather than Ca. Liberibacter asiaticus
What is Epidemiology? cont.

- **Host:** Organism (potentially) infected by another organism
  - Alternaria Brown spot: Tangerines and tangerine hybrids

- **Population:** A population phenomena of both host and pathogen
  - Dynamic processes often described with statistics or mathematical models

- **Time and Space:** Two dimensions of interest
  - Change over time or over a grove and sometimes both
Many Levels to Study Organisms

Molecular
Cellular
Tissue
Organ
Individual
Population
Community
System

Epidemiology
« Science of disease in populations »
(Vanderplank, 1963)
Broad Definition

- Epidemic does NOT mean widespread or high levels of disease
  - Pandemic is the correct term for widespread or high levels of disease
- Example: *Phytophthora infestans* (Potato Late Blight)
  - Field with 4 million plants ($4 \times 10^6$)
  - 1 lesion/plant = 0.1% severity ~ 1/1000 leaf surface covered by lesions
  - Limit of detection

LV Madden
Late Blight Example cont.

- time (t)=0 days (d) disease severity (y)=0.1% → t=90d y=100%
  ✓ 1000 fold change

- t=30d y=1% → t=90d y=100%
  ✓ 100 fold change

- t=0d y=1 lesion/field (0.1/4X10^6) → t=90d y=100%
  ✓ y=1 lesion/plant (0.1% severity or 0.1/4X10^6 lesions/field) – 4X10^6 fold change
Late Blight Example cont.

- How to determine when the epidemic started?
- Does scale change the biological processes that occur?
- Change in population disease intensity is an epidemic
Disease Triangle

- Ecology of disease
- Principle of disease triangle still relevant but on population level
  - Emphasis on interactions
- Time or space or humans or vectors?
  - Awkward since limited to 3 dimensions

Epidemiology can be either...

- Descriptive
  - Where; when; what
  - Has been used to fill in disease cycles

  OR

- Quantitative
  - How many ‘propagules’ are needed
  - How much disease is present
  - How fast does disease develop
  - How far can propagules travel
Tool Box

- Classical plant pathology
  - Culturing, microscopy, Koch’s postulates…

- Techniques from complimentary fields
  - Agronomy, botany, ecology, entomology, genetics, statistics, mathematics, meteorology etc.
Host Growth and Susceptibility

- Melanose control requires good coverage with fungicide on the fruit surface for nearly 3 months
- Copper is most common fungicide
  - does not redistribute well on plant surface
  - has good residual activity
  - Can build up in soil
  - Phytotoxicity
- Foreseen problems?
Host Growth and Susceptibility

- Field study conducted to compare number of applications with same amount of copper
- More sprays reduced disease
  - Covered up areas on fruit exposed by growth
  - Less wash off

<table>
<thead>
<tr>
<th>Product</th>
<th>No. of applications</th>
<th>1995 Severity rating (0-5)</th>
<th>1996 Severity rating (0-5)</th>
<th>1997 Severity rating (0-5)</th>
<th>Marketable fresh (%) 1995</th>
<th>Marketable fresh (%) 1996</th>
<th>Marketable fresh (%) 1997</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kocide</td>
<td>0</td>
<td>2.5 a</td>
<td>1.6 a</td>
<td>3.0 a</td>
<td>11 a</td>
<td>51 b</td>
<td>1 c</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1.4 b</td>
<td>1.0 b</td>
<td>1.8 b</td>
<td>61 b</td>
<td>90 a</td>
<td>40 b</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.5 b</td>
<td>1.0 b</td>
<td>1.9 b</td>
<td>60 b</td>
<td>87 a</td>
<td>35 b</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1.4 b</td>
<td>1.1 b</td>
<td>1.5 bc</td>
<td>61 b</td>
<td>83 a</td>
<td>37 ab</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1.1 c</td>
<td>0.9 b</td>
<td>1.2 c</td>
<td>79 a</td>
<td>92 a</td>
<td>72 a</td>
</tr>
<tr>
<td>Champ</td>
<td>1</td>
<td>1.7 b</td>
<td>1.0 b</td>
<td>...</td>
<td>48 cd</td>
<td>88 a</td>
<td>...</td>
</tr>
<tr>
<td>Formula II</td>
<td>2</td>
<td>1.7 b</td>
<td>1.1 b</td>
<td>...</td>
<td>47 cd</td>
<td>85 a</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1.8 b</td>
<td>1.0 b</td>
<td>...</td>
<td>43 d</td>
<td>87 a</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1.6 bc</td>
<td>1.0 b</td>
<td>...</td>
<td>54 bc</td>
<td>84 a</td>
<td>...</td>
</tr>
</tbody>
</table>

Timmer et al, 1998
Host Growth and Susceptibility

- Copper residue can vary by year depending on rain.
- Model developed to account for growth and rain.

Table 2. Effect of fruit growth and rainfall on the copper residues remaining on fruit after application of fungicides.

<table>
<thead>
<tr>
<th>Product</th>
<th>Sample date</th>
<th>Rainfall (mm)</th>
<th>Fruit surface area (cm²)</th>
<th>Metallic Cu residue</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>mg/fruit³</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>µg/cm² fruit surface²</td>
</tr>
<tr>
<td>Kocide 2000³</td>
<td>1 May 96</td>
<td>0</td>
<td>138 ± 19</td>
<td>1.93 ± 0.45 (100)</td>
</tr>
<tr>
<td></td>
<td>15 May</td>
<td>39</td>
<td>382 ± 72</td>
<td>1.48 ± 1.40 (77)</td>
</tr>
<tr>
<td></td>
<td>29 May</td>
<td>48</td>
<td>597 ± 105</td>
<td>1.03 ± 0.35 (33)</td>
</tr>
<tr>
<td>Champ Formila II²</td>
<td>1 May 96</td>
<td>0</td>
<td>75 ± 33</td>
<td>0.99 ± 0.53 (100)</td>
</tr>
<tr>
<td></td>
<td>15 May</td>
<td>39</td>
<td>373 ± 65</td>
<td>0.60 ± 0.82 (61)</td>
</tr>
<tr>
<td></td>
<td>29 May</td>
<td>48</td>
<td>631 ± 118</td>
<td>1.04 ± 0.37 (102)</td>
</tr>
<tr>
<td>Kocide 2000²</td>
<td>6 May</td>
<td>0</td>
<td>308 ± 102</td>
<td>1.33 ± 1.03 (100)</td>
</tr>
<tr>
<td></td>
<td>20 May</td>
<td>0</td>
<td>374 ± 29</td>
<td>0.55 ± 0.26 (20)</td>
</tr>
<tr>
<td></td>
<td>3 June</td>
<td>47</td>
<td>552 ± 36</td>
<td>0.36 ± 0.21 (20)</td>
</tr>
<tr>
<td></td>
<td>18 June</td>
<td>163</td>
<td>495 ± 27</td>
<td>0.13 ± 0.08 (7)</td>
</tr>
</tbody>
</table>

¹ Total rainfall since the application of fungicide.
² Fruit surface area ± standard deviation.
³ Total copper residues per fruit in mg ± standard deviation. Numbers in parentheses are the percentages of initial residue remaining.
⁴ Copper residue per cm² of fruit surface ± standard devation. Number in parentheses are the percentages of the initial residue.
⁵ Applied on 30 April 96 at 9.1 kg metallic copper/ha.
⁶ Applied on 30 April 96 at 4.5 kg metallic copper/ha.
⁷ Applied 5 May 97 at 4.5 kg metallic copper/ha.

Timmer et al, 1998
Host Growth and Susceptibility

- With no rain, copper residues will decline quickly with rapid growth in early season.
- Rain accelerates the process.
- Melanose cannot infect fruit > 8 cm.
Host Growth and Susceptibility

- Cultivar susceptibility and age related or ontogenic resistance affects epidemic
- Which fruit is most susceptible?
- Any idea what disease this might be?
- As fruit become larger less susceptible
- Time is also a factor

Graham et al, 1992
Host Growth and Susceptibility

- Why do fruit become more then less susceptible?
  - Similar phenomenon in leaves
  - Stomates opening as fruit become larger?
  - *Xanthomonas citri* subsp. *citri* may need expanding tissue to be able to infect
    - Grapefruit expands for longer during the season?
  - Surface waxes may not allow for as much wetting
Fruit Growth

- Does Grapefruit expand for longer?
Stomates and Canker

- It was thought that stomate size and density would affect canker severity
  - But no relationship

- Host susceptibility on leaves
  - Other factors
  - Not yet understood

**TABLE 1. Characteristics of stomata on leaves of two-thirds and full expansion of field-grown citrus cultivars varying in susceptibility to citrus canker**

<table>
<thead>
<tr>
<th>Cultivar*</th>
<th>Large stomata</th>
<th>Two-thirds expansion</th>
<th>Small stomata</th>
<th>Large Stomata</th>
<th>Full expansion</th>
<th>Small stomata</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area (μm²)</td>
<td>Area (μm²)</td>
<td>Density (no./0.059 mm²)</td>
<td>Open (%)</td>
<td>Area (μm²)</td>
<td>Area (μm²)</td>
</tr>
<tr>
<td>Red Blush grapefruit</td>
<td>46.5 a</td>
<td>13.4 a</td>
<td>48.0 a</td>
<td>65.0 a</td>
<td>61.8 b</td>
<td>14.3 a</td>
</tr>
<tr>
<td>Marsh grapefruit</td>
<td>37.8 ab</td>
<td>4.5 c</td>
<td>30.3 b</td>
<td>34.2 bc</td>
<td>60.7 b</td>
<td>13.7 a</td>
</tr>
<tr>
<td>Swingle citrumelo</td>
<td>35.1 ab</td>
<td>10.1 b</td>
<td>33.9 b</td>
<td>24.8 c</td>
<td>90.9 a</td>
<td>16.4 a</td>
</tr>
<tr>
<td>Valencia sweet orange</td>
<td>45.2 a</td>
<td>9.9 b</td>
<td>45.0 a</td>
<td>54.4 a</td>
<td>59.9 b</td>
<td>15.3 a</td>
</tr>
<tr>
<td>Orlando tangelo</td>
<td>28.5 b</td>
<td>6.1 c</td>
<td>49.2 a</td>
<td>21.9 cd</td>
<td>50.9 b</td>
<td>14.8 a</td>
</tr>
<tr>
<td>Sour orange</td>
<td>22.6 b</td>
<td>3.7 c</td>
<td>32.4 b</td>
<td>10.2 d</td>
<td>41.7 b</td>
<td>13.3 a</td>
</tr>
<tr>
<td>Cleopatra mandarin</td>
<td>27.2 b</td>
<td>4.0 c</td>
<td>34.8 b</td>
<td>38.0 b</td>
<td>62.6 b</td>
<td>14.0 a</td>
</tr>
</tbody>
</table>

* Cultivars are listed in descending order of susceptibility to citrus canker based on artificial inoculations and field observations.

a Area of the opening of antichambers (see Fig. 1).

bc Percentage of stomata with open antichambers (see Fig. 1).

Means (of 10 fields, each measuring 0.059 mm²) in columns followed by the same letter do not differ significantly according to the Student-Newman-Keuls multiple range test (p ≤ 0.05).
Host Growth and Susceptibility

- Citrus leaves grow too fast to be effectively protected by available fungicides
  - pyraclostrobin, copper hydroxide, ferbam
  - Example is the case of Alternaria brown spot
  - Similar for Melanose and Citrus Scab

Mondal et al., 2007
Environment
Environment

- Can affect whether a pathogen will infect
  - *Alternaria alternata* and *Xanthomonas citri* subsp. *citri* cannot infect if it is dry

- Pathogen dispersal is affected by environment
  - *Diaporthe citri* conidia are distributed by rain

- Environment influences inoculum production
  - *Mycosphaerella citri* pseudothecia require wetting and drying cycle to be initiated and mature

- Other examples?
Wind

- Tricky to work with in lab!

Gottwald and Graham, 1992
Effect of Wind on Canker

- This is how it was determined that 8 m/s (18 mph) of wind driven rain was needed to force *X. citri* subsp. *citri* cells into a leaf.

- Leaf expansion was also important
  - Why?
Effect of Wind on Canker

- Pressure also affected number of bacteria in leaves

- What is the difference in the two leaf surfaces?
What Environmental Stimulus is Needed?

- Many environmental stimuli were tested to see when *A. alternata* spores were released
  - Inside artificial chamber

Timmer et al., 1988
Environmental Stimuli cont.

- Rain and drops in relative humidity are not clearly distinguishable but both contribute to spore release.
- In field conidia production and infection weakly associated with leaf wetness duration.

Timmer et al., 1988
When are Conidia Produced?

- Field spore trapping of *Pseudocercospora angolensis*
  - Relationship with temperature and rainfall more evident
  - Similar pattern with relative humidity
  - Interactions between variables not tested

Pretorius, 2005
Infection Conditions Alternaria Brown Spot

- Optimum temperatures 23-27°C
  - Can get infection between 17-32°C
- Infection can occur with as little as 4-6 hours of leaf wetness but disease severity increases with leaf wetness
- Are there other factors that could affect this relationship?

Canihos et al., 1999
Infection Conditions Complicated by Host

- Not all cultivars react to the same infection conditions identically
  
  ✓ All susceptible hosts
  
  ✓ Nova needs > 30 hours of leaf wetness to have same level of infection as Minneola

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Mondal et al. 2008
Probability of Disease

- Model developed from growth chamber data

- Prob.’s calculated for each lesion rating at the leaf wetness and temperature combination

![Diagram of probability of disease model](image)
Disease Probabilities cont.

- Probabilities change with cultivar
- Sunburst is much less susceptible than Dancy
- Reflected in graphs
Lots of Interest in Leaf Wetness and Temperature

- Conidia germinate
  - 6 hrs at 16 °C
  - 4 hrs 20 to 28 °C
- Literature has varying times and temperatures needed for infection
- Optimum temp determined to be 24-28 °C

Agostini et al., 2003
Infection Conditions for Scab

- Contradictory information in the literature about leaf wetness and temperature
  - Optimal temperature range
    - 23.5 to 27 °C
  - Optimal leaf wetness
    - Between 12 and 24 hrs

Agostini et al., 2003
Temperature Effect can Change with Disease Evaluation

- Phytophthora palmivora - which disease?
- What is the difference between incidence and severity?
  ✓ Incidence – disease status of plant units as individual or pieces such as number of proportion of leaves with disease
  ✓ Severity - area of disease
- How could this be important in an epidemic?

Timmer et al., 2000
Leaf Wetness and Temperature also Important for Inoculum Production

- Sporangia production highly dependant on both factors
- Interaction also important

✓ What is the significance of an interaction?

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>$F$</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (Tp)</td>
<td>3</td>
<td>35.25</td>
<td>0.0001</td>
</tr>
<tr>
<td>Time (Tm)</td>
<td>4</td>
<td>79.85</td>
<td>0.0001</td>
</tr>
<tr>
<td>$Tp \times Tm$</td>
<td>12</td>
<td>10.35</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

Timmer et al., 2000
Pathogen Effects

- Questions of interest about the pathogen:
  - What is required to produce inoculum?
    - Are there environmental or other factors that contribute to inoculum production
  - How much inoculum is present?
    - Can affect how quickly an epidemic can become established and move into exponential phases
  - When is the inoculum present?
    - No inoculum; no disease
Spore Traps

Impact Traps/Volumetric
Allows for sampling spores in a volume of air but not over time

- Spores are counted under the microscope
- Can be tedious and requires training
- Some new versions allow for PCR identification

Burkard Spore Trap
Allows for sampling spore patterns over time
Ascospore Ejection Pattern

- *Phyllosticta* spp. ascospore ejection is reported to be triggered by rain.
- In Brazil wetness duration was more important.
- Very frequent rain events; ascospores cannot mature fast enough to eject with each rain event.
- Cannot forecast infection event based on rainfall.

Reis et al., 2006
Phyllosticta spp. Ascospore Release in Florida

Week of May 13-20, 2010

Date | Thu 13 | Sat 15 | Mon 17 | Wed 19 | Fri 21
---|---|---|---|---|---
Number of Guignardia ascospores | 0 | 25 | 50 | 75 | 100

Week of May 21-28, 2010

Date | Fri 21 | Sun 23 | Tue 25 | Thu 27
---|---|---|---|---
Number of Guignardia ascospores | 0 | 25 | 50 | 75
Pathogen Populations

- How many nurseries have metalaxyl resistant isolates of *Phytophthora nicotianae*?
- What proportion of the population?
- If nurseries have resistant isolates can spread around state

Table 1. Survey of Florida citrus nurseries to determine the prevalence of metalaxyl-resistant isolates of *Phytophthora nicotianae*

<table>
<thead>
<tr>
<th>Nursery operations</th>
<th>Site</th>
<th>Phytophthora control program*</th>
<th>No. of blocks sampled</th>
<th>Propagules/cm³</th>
<th>Metalaxyl-resistant (%)³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immokalee</td>
<td>1</td>
<td>B</td>
<td>7</td>
<td>52</td>
<td>0-128</td>
</tr>
<tr>
<td>La Belle I</td>
<td>2</td>
<td>A</td>
<td>6</td>
<td>60</td>
<td>0-152</td>
</tr>
<tr>
<td>La Belle II</td>
<td>1</td>
<td>A</td>
<td>2</td>
<td>0</td>
<td>...</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>A</td>
<td>5</td>
<td>56</td>
<td>0-126</td>
</tr>
<tr>
<td>Florida</td>
<td>D</td>
<td>A</td>
<td>6</td>
<td>0</td>
<td>...</td>
</tr>
<tr>
<td>Lake Placid</td>
<td>D</td>
<td>A</td>
<td>8</td>
<td>9</td>
<td>0-66</td>
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<tr>
<td>Sebring</td>
<td>C</td>
<td>A</td>
<td>48</td>
<td>10</td>
<td>0-26</td>
</tr>
<tr>
<td>Avon Park I</td>
<td>A</td>
<td>B</td>
<td>8</td>
<td>48</td>
<td>0-104</td>
</tr>
<tr>
<td>Avon Park II</td>
<td>B</td>
<td>B</td>
<td>11</td>
<td>20</td>
<td>0-58</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>7</td>
<td>18</td>
<td>0.70</td>
<td>0.70</td>
</tr>
</tbody>
</table>

* A = metalaxyl used exclusively; B = metalaxyl and fosetyl-Al alternated; C = fumigation only; D = fumigation and metalaxyl and fosetyl-Al alternated.

* Percentage of isolates able to grow on media containing 1.0 μg/ml of metalaxyl.
Are Metalaxyl Resistant Isolates as Fit as Sensitive Ones?

- Roots: similar proportion found as added
  ✓ Resistant slightly more
- Soil: more resistant propagules than sensitive
  ✓ More propagules recovered than applied (RYT)
- Resistant strain more aggressive – more likely to spread

Timmer et al., 1998
Bacterial Dynamics

- Very few bacteria need to penetrate leaves to initiate an infection
- In 1 week have $10^7$ cells in a lesion
  - Many propagules formed!
  - This is relatively slow for bacteria

Graham et al., 1992
Greasy Spot Inoculum Production

- Wetting is critical for pseudothecia production
- Most ascospores produced with the 3-day per week wetting scheme
- Wetting scheme also changes peak ascospore ejection
Optimal Temperatures for Ascospore Production

- Spores trapped with a Burkhard trap
  - Spores are produced within tight temperature range
  - Somewhat unusual but in Florida conditions are within the optimal range often

Mondal and Timmer, 2002
Statistics and Mathematics

- Much of epidemiology uses statistics especially the quantitative work
- Much of the theoretical modeling that is undertaken uses a combination of mathematics and statistics
- A good working knowledge of statistics is needed to be a good epidemiologist and/or ecologist
  - At least know when to collaborate!
Disease Progress over Time

- Time is a fundamental factor in an epidemic since we are usually measuring change in disease status over time
  - Not a static process
  - Why some people include time in the disease triangle
- Often disease progress curves used to compare epidemics
Disease Progress of Canker Epidemic

- Disease progress curves at 5 urban sites
  - A is cumulative data
  - B is the rate of change between each time point
- Can see this is a very dynamic process as the rate of disease is not continuous

Gottwald et al, 2002
Epiphytic Growth and Severity

- Greasy spot severity is influenced by when the epiphytic growth of *Mycosphaerella citri* occurs.

- The severity that occurs with levels of epiphytic growth changes over time.
  - Disease severity does not track epiphytic growth especially in the winter.

Mondal and Timmer, 2003
Disease Progress in Space

- There are two aspects of general interest
  - Dispersal gradients
  - Spatial patterns

- Dispersal gradients tell how far an organism can spread

- Spatial patterns can give a sense of how the organism spreads
  - Splash, wind, vector etc.
  - Can indicate unforeseen dynamics in diseases
How Far Can A Sporangia Splash?

- Depends on species
  - *P. palmivora* splashes further than *P. nicotianae*
- Some strains travelled further than others
- Means that *P. palmivora* is more likely to move by splash and spread further

Timmer et al., 2000
Horizontal and Vertical Movement

- *Phytophthora palmivora* travels in 2 dimensions with water droplets

- Appears that majority of sporangia travel down
  - Greater number of colonies/sporangia below inoculum source

Timmer *et al.*, 2000
Canker Frequency and Distance

- Tried to find a distance where it was unlikely an infected tree escaped
  - $579\ m = 1900\ ft$

Gottwald et al, 2002
Common Spatial Patterns

**Uniform**
Evenly spaced pattern
Unusual in biological systems
Sometimes from some sort of application mistake

**Random**
Occurs if disease process is independent of neighbors

**Aggregated**
Occurs when the disease process depends on distance among individuals
How Many Samples Do I Need?

- Want an accurate estimate of pathogen population
- Need to know whether the pathogen is common
- From the patterns (with several equations) arrived determined that:
  - 1, 2, 3, 4, 5 or ten samples/tree were taken then needed to sample 22, 13, 10, 8, 7 or 5 trees respectively

Timmer et al., 1998
Urban Citrus Canker

- What sort of pattern is this?
- Note how few trees were affected initially

Gottwald et al, 2002
Citrus Scab Spread from a Foci

Gottwald, 1995
What Type of Spread Occurs with HLB

- Wanted to know if spread was from tree to tree in grove or from outside grove
- Used stochastic modeling to develop plots
  - MCMC posterior densities
- These plots show most spread was mainly background (outside)

Gottwald et al, 2008
Spread Within Grove

- Spread was mid-range distance so not spreading to nearest neighbors but to nearby trees

Gottwald et al, 2008
What Kind of Spread is Occurring Here?

Gottwald et al, 2008
Spatial Patterns

- Could see with both Canker and Scab that the most likely trees to be infected were near by
- Scab is splash distributed
- Canker moves with wind-driven rain
- Also useful for understanding vectored diseases
  - There is both external and medium range movement of infectious Asian citrus psyllids
Disease Forecasting

- Two disease forecasting models used in citrus
  - Alter-Rater
  - Post-bloom Fruit Drop
- Designed so that the most effective timing of spray applications can be used
- Also predict decay of copper residue on fruit surfaces
ALTER-RATER: A Forecasting System

- Weather-based point system to better time fungicide applications
- Points assigned based on:
  - Rain fall and leaf wetness
  - Average daily temperature
- Thresholds vary by cultivar susceptibility
- Has been integrated into FAWN weather system
# The ALTER-RATER
## Suggested Threshold Scores

<table>
<thead>
<tr>
<th>Score</th>
<th>Situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>Heavily infested Minneola, Dancy, Orlando, Sunburst; Many flatwood groves, east coast, and SW Florida.</td>
</tr>
<tr>
<td>100</td>
<td>Moderately infested Minneola or Dancy, many Murcotts; Ridge and north Florida groves.</td>
</tr>
<tr>
<td>150</td>
<td>Light infestations, any variety, mostly Ridge and north Florida groves.</td>
</tr>
</tbody>
</table>
## ALTER- RATER Daily Points

<table>
<thead>
<tr>
<th>Rain &gt; 0.1 inch</th>
<th>LW &gt; 10 hr</th>
<th>Avg daily Temp</th>
<th>Assigned score</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>+</td>
<td>68-83</td>
<td>11</td>
</tr>
<tr>
<td>+</td>
<td>+</td>
<td>&gt; 83</td>
<td>8</td>
</tr>
<tr>
<td>+</td>
<td>+</td>
<td>&lt; 68</td>
<td>6</td>
</tr>
<tr>
<td>+</td>
<td>_</td>
<td>68-83</td>
<td>6</td>
</tr>
<tr>
<td>+</td>
<td>_</td>
<td>&gt; 83</td>
<td>4</td>
</tr>
<tr>
<td>+</td>
<td>_</td>
<td>&lt; 68</td>
<td>3</td>
</tr>
<tr>
<td>_</td>
<td>+</td>
<td>68-83</td>
<td>6</td>
</tr>
<tr>
<td>_</td>
<td>+</td>
<td>&gt; 83</td>
<td>6</td>
</tr>
<tr>
<td>_</td>
<td>+</td>
<td>&lt; 68</td>
<td>4</td>
</tr>
<tr>
<td>_</td>
<td>_</td>
<td>68-83</td>
<td>3</td>
</tr>
<tr>
<td>_</td>
<td>_</td>
<td>&gt; 83</td>
<td>0</td>
</tr>
<tr>
<td>_</td>
<td>_</td>
<td>&lt; 68</td>
<td>0</td>
</tr>
</tbody>
</table>
Original PFD Model

\[ y = -13.63 + 1.16\sqrt{TD} + 0.48\sqrt{R \times 2500} + 1.77\sqrt{LW \times 5} \]

\[ y = \text{Percentage of flowers infected 4 days in the future} \]

\[ TD = \text{total number of infected flowers on 20 trees;} \]
\[ \quad \text{however if } TD < 75 \text{ then } TD = 0 \]

\[ R = \text{rainfall total for the last 5 days in inches} \]

\[ LW = \text{Average number of hours of leave wetness daily for the last 5 days - 10 hours} \]

http://pfd.ifas.ufl.edu/
When to Follow the Model

- A fungicide application is indicated if these three criteria are met:
  1) the model predicts a disease incidence of greater than 20%
  2) sufficient bloom is present or developing to represent a significant portion of the total crop
  3) no fungicide application has been made in the last 10-14 days.
How the Citrus Copper Application Scheduler Operates

- Incorporates rainfall data from FAWN (Florida Automated Weather Network- www.fawn.ifas.ufl.edu) or own weather data
- Incorporates data on copper residue degradation
- Incorporates fruit growth size
Steps to Achieve Daily Prediction

1) Calculate initial copper residue from first spray

2) Reduce the residue according to the fruit growth

3) If rain on current day, reduce residue proportionally to the actual residue

4) If spray on current day, sum existing residue with new residue

5) Current day residue

Daily loop

Rainfall
Spray Dates
Spray Volume
Spray Concentration
Scion
Fruit Position

Zortea et al. (2012)
Series of Equations

- Model is built on series of equations
  - Copper application residue
    - \( DEPO = (0.6399 + 0.005539 \times V)A\left(\frac{C}{4}\right) \)
  - Fruit growth
    - \( AREA = MAX \times e^{\ln\left(\frac{MIN}{MAX}\right)e^{-BT}} \)
  - Residue for each day
    - \( RESIDUE = \frac{DEPO}{AREA} \)
  - Residue loss
    - \( rLost = RESIDUE (0.016535R) \)

Zortea et al. (2012)
To Use

- Select weather option and scion first

- Can use metric units
Enter Bloom Date
Every 21-day Schedule

- Have insufficient coverage for 6 days

- About perfect timing for third spray
Coverage Optimized with Model

- Moved first spray up 8 days
- Did not move third spray
Improvements in Progress

- Some operations cannot easily take advantage of model
  - Equipment movement
  - Need to schedule in advance
- Developed optimized schedule for such operations
  - Historical weather per region
  - Bloom date
Traditional Versus Optimized

- 21-day schedule (top) had 2 major gaps in coverage

- Optimized schedule reduced gaps in coverage but did not eliminate
Further Improvements

- Original model not designed to predict past mid July
  - Why?
- Need residue data for summer
- What diseases?
- Fruit growth too

![Graph showing average copper/surface area and total daily rainfall over the months of June to November for Grapefruit. The graph includes data peaks and troughs indicating variability in rainfall and copper levels throughout the summer months.]