Precise placement and variable rate fertilizer application technologies

Arnold W Schumann
Precision Agriculture (PA) for Horticulture

- Technology for growing horticultural crops more precisely or efficiently

Specific Objective:

- Retain water and nutrients in the root zone
The Site-Specific Management (SSM) Concept

- SSM is a crop management strategy of PA
- SSM addresses within-field variability by optimizing inputs such as pesticides and fertilizers on a point-by-point or small area basis
- Nutrients are applied only as needed within a field, rather than applying them uniformly across the entire field for the average field requirements
- SSM relies on accurate spatial data of important soil and crop factors and their interpretation into variable fertilizer rates targeted only to crop canopies and root zones
PA – SSM techniques which can help

1. Collect spatial data of pre-existing conditions in the field
   - Crop plant locations, condition & size, yield, soil variability (e.g. precision seed mapping, remote sensing, yield monitoring, chlorophyll sensing)

2. Apply precise fertilizer amounts to the crop as, when and where needed
   - Variable rate technology; sensors, prescription maps, microcontrollers, GPS, automation

3. Record detailed logs of all fertilizer applications for nutrient tracking, spatial and temporal mapping (automated by computers / GIS)
COMMON ELEMENTS OF A CITRUS PRECISION FARMING SYSTEM

- Remote sensing
- Geographic Information System
- Global Positioning System
- Mobile computing & Data storage
- Soil mapping
- Variable rate inputs
- Yield monitoring
- Canopy measurement
Weak soils
Remote Sensing – NDVI of Citrus

Variation of Soil Color in different productivity zones

Depth (cm)

0-15

15-30

30-45

45-60

Very Poor

Poor

Medium

Good

Very Good
Spatial variability in strawberry fields; plant size, vigor, yields, nutrient utilization

Photo by J. Noling
Embedded microcontrollers are specialized computers used to control and automate specific processes in precision agriculture. These computers are usually built to very rugged standards and have limited user interfaces but powerful automatic data logging capabilities for recording all fertilizer or water applications.

- Hand-held computer with ArcPad GIS
- Variable rate controller for fertilizer spreaders
- Automatic irrigation system controller
Soil, Crop Yield and Canopy Mapping

- Ground-based sensor surveying and mapping of soils, crop yield and canopy characteristics is an alternative to remote sensing.

- The resolution and quality of ground-sensed data is often superior due to lack of atmospheric and seasonal illumination effects.

- **Examples:**
  - Greenseeker NDVI and other optical canopy sensors, handheld Minolta SPAD meter
  - Crop canopy size sensors
  - Yield monitors for crop harvesters
  - Soil EC sensing by electromagnetic induction
The Greenseeker® NDVI sensor

Normalized difference vegetation index (NDVI)

\[ \text{NDVI} = \frac{(\text{NIR} - \text{Red})}{(\text{NIR} + \text{Red})} \]

The Greenseeker uses its own LED light source.
Example in Strawberries

- Greenseeker NDVI was tested on two motorized platforms during winter 2006/07

- Greenseeker NDVI was correlated with incidence of nematode damage in 15.2-m row sections of strawberry fields (dead, small, medium, large plants)
Goodson Back Field

Exponential model (Co = 5270.00000; Co + C = 11440.00000; Ao = 36.60; r² = 0.98; RSS = 1118125.)

Range=24 m
Kriging interpolation of NDVI using exponential model

Healthy plants

Moderate nematode infestations

Severe nematode infestations

Range (24 m) = extent of spatial correlation
Example: Water Table Mapping

- survey orchard with EMI instruments – ground conductivity ~5 feet deep

- manual EMI readings and water depth at wells

- automated with PC, GPS and vehicle/sled for whole orchard (5438 measurements)
Revell grove

Water table (cm):
- 25 - 95
- 95 - 124
- 124 - 149
- 149 - 174
- 174 - 287

Survey boundary
Other profiling technologies:
Veris 3100 soil EC mapping system

- coulter electrode system
- rugged and durable
- shallow depth
- does not tolerate dry soil

(www.veristech.com)
Ground Penetrating Radar (GPR)

- Radar signal penetrates soil and reflects from dielectric interfaces (e.g., clay pan)
- Requires interpretation
- Slow
- Expensive
- Multi-layer information

- Maps of subsoil features produced with GPS/GIS
Fruit tub mapping:  
May 2004 harvest

Automatic tub position logger  
1 tub = 0.41 Mg (900 lb) fruit
Fruit yield 2004
Mean = 336 boxes/ac

Minimum 181 boxes/ac

Maximum 543 boxes/ac

3x difference in yield; target the weak areas for improvement using variable rate equipment
Ultrasonic Canopy Measurement
Ultrasonic canopy measurement

- Tree canopy
- Ultrasonic beam
- Ultrasonic transducer
- PVC mast
- DGPS antenna
- Ground level
- Vehicle
- H_T
- D_1
- D_2
- D_S
- D_D
- D_R
- D_R

(1)

(10)
Ultrasonic canopy measurement

LEFT ultrasonic sensor array

RIGHT ultrasonic sensor array

Ground speed (m/s): 2.4
Temperatures
Air: 86
Case: 98

Frequency (Hz): 12
Buffers: 4
Records: 32598
GPS Fix: A
Track (deg): 356.1
Scans: 2
Checksum error: 645

LEFT tree canopy measurements
Area (sq m) 36.8
Height (m) 6.3

RIGHT tree canopy measurements
Area (sq m) 17.9
Height (m) 4.8
Ultrasonic canopy volume tree data
Variable Rate Fertilization

- Variable rate application of granular fertilizers (VRF) allows improved placement in root zones and rate matching of fertilizers to crop requirements.
- The two main functions of VRF are:
  1. To find the best fertilizer rate to match the crop and soil requirements (sensing) and
  2. To place the fertilizer as accurately as possible in the root zone or canopy (GPS/GIS)
- Implies that no fertilizer is ever applied to bare soil where there are no active crop roots to absorb the nutrients.
Granular fertilizer spreaders with variable rate capability can reduce fertilizer use in citrus by up to 40% (Zaman et al., 2005)
Location of the main root zones in citrus trees

- 20 x 10 foot spacing
- 25 x 15 foot spacing

Root zones

Fertilizer bands

wasted fertilizer when VRF is not used

Adapted from Morgan, pers. comm.
THEREFORE: VRF is most effective in widely spaced orchards with high spatial variability; e.g. 40-ac ‘Valencia’ grove.
A key component to the success of VRF is the real-time canopy sensing system which measures the size of the trees before the appropriate dose of fertilizer is dispensed.
The tree sensing system must be capable of rapid measurement and synchronization of the rate controller with vehicle speed (‘look-ahead’).
The VRF control system must be capable of rapid on-off transitions so that bare ground is not fertilized and tree canopy is correctly targeted.
Variable rate controllers

Mid-Tech Legacy 6000

Dickey-John Land Manager II
Operation of Canopy Sensors

- **Row spacing**
- **N fertilizer rate** = 240 lb/ac/y (BMP max)

- **18' height**
  - 100% rate

- **13' height**
  - 83% rate

- **8' height**
  - 66% rate

- **3' height**
  - 50% rate

- **0' height**
  - 0% rate

Infrared light beams and Sensors indicate different rates based on tree height.
SENSOR ANGLE IS ADJUSTABLE & DEPENDS ON TARGET HEIGHT
Fertilization of mixed tree sizes; all ages

\[ \ln(Y) = 0.5106X + 3.084 \]

\[ R^2 = 0.99 \]

(sensor 1; width only, no hedgerow)

(sensor 2; height)

(sensor 3; height)

(sensor 4; height)
Look-ahead compensation

- Look ahead is a dynamic time delay calculated with ground speed and is essential to offset the fertilizer discharge point from the canopy sensing point.
- It includes the inherent mechanical, hydraulic and software delays in the system.

(Video clip)
Research: Testing & Improvement of VRF spreaders

- Accuracy of fertilizer rate dispensed according to tree canopy size is important.
- Accuracy of fertilizer placement according to canopy size and look-ahead is equally important.
- Good performance relies on well-matched components with correct calibration & tuning to achieve rapid VRF response times.

Leachates were collected at 1.5-m soil depth:

- NO₃-N in VRF treatments 1.5 to 4.5 mg/L
- NO₃-N in conventional treatments 14.0 to 28.5 mg/L
## Response of two VRF control systems

Table 1. Summary of performance timing parameters obtained for two VRA systems

<table>
<thead>
<tr>
<th>Test system</th>
<th>Rate change (kg/ha)</th>
<th>Delay time (s)</th>
<th>Transition time (s)</th>
<th>Response time (s)</th>
<th>Transition distance&lt;sup&gt;1&lt;/sup&gt; (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0-560</td>
<td>0.72</td>
<td>0.51</td>
<td>1.2</td>
<td>1.3</td>
</tr>
<tr>
<td>1</td>
<td>560-0</td>
<td>0.15</td>
<td>0.30</td>
<td>0.45</td>
<td>0.75</td>
</tr>
<tr>
<td>1</td>
<td>280-560</td>
<td>0.42</td>
<td>2.8</td>
<td>3.2</td>
<td>7.0</td>
</tr>
<tr>
<td>1</td>
<td>560-280</td>
<td>0.51</td>
<td>3.1</td>
<td>3.7</td>
<td>7.8</td>
</tr>
<tr>
<td><strong>Mean ±SE</strong></td>
<td><strong>-</strong></td>
<td><strong>0.45 ±0.24</strong></td>
<td><strong>1.7 ±1.5</strong></td>
<td><strong>2.1 ±1.6</strong></td>
<td><strong>4.2 ±3.7</strong></td>
</tr>
<tr>
<td>2</td>
<td>0-560</td>
<td>0.16</td>
<td>0.28</td>
<td>0.44</td>
<td>0.70</td>
</tr>
<tr>
<td>2</td>
<td>560-0</td>
<td>0.16</td>
<td>0.30</td>
<td>0.46</td>
<td>0.75</td>
</tr>
<tr>
<td>2</td>
<td>280-560</td>
<td>0.13</td>
<td>0.19</td>
<td>0.31</td>
<td>0.48</td>
</tr>
<tr>
<td>2</td>
<td>560-280</td>
<td>0.12</td>
<td>0.20</td>
<td>0.32</td>
<td>0.50</td>
</tr>
<tr>
<td><strong>Mean ±SE</strong></td>
<td><strong>-</strong></td>
<td><strong>0.14 ±0.021</strong></td>
<td><strong>0.24 ±0.056</strong></td>
<td><strong>0.38 ±0.078</strong></td>
<td><strong>0.61 ±0.14</strong></td>
</tr>
</tbody>
</table>

<sup>1</sup> calculated for a speed of 2.5 m/s

System 1 = MidTech; System 2 = Dickey-John
Regression analysis for 15 trees

\[ Y = 0.757X + 83.2 \]
\[ R^2 = 0.85 \]
\[ \text{RMSE} = 62.5 \text{ kg/ha} \]

- **BIAS:**
  - Small trees over-fertilized
  - Large trees under-fertilized

**SYSTEM 1**
Regression analysis for 15 trees

SYSTEM 2

\[ Y = 0.915X + 28.2 \]

\[ R^2=0.99 \]

\[ RMSE=14.9 \text{ kg/ha} \]
A well-tuned VRF system can correctly and precisely fertilize any size tree
Focus for Future Research

- Improving crop sensors: existing canopy size sensors don’t discern healthy from dead plants – not fertilizing sick or dead plants is an opportunity for conserving more nutrients

- Variable rate irrigation: if water could be applied site specifically according to soil and crop needs, then nutrient retention in the root zone would be improved

- More precise data on where crop plants (and planted seeds) are: centimeter map accuracy with RTK-DGPS and automatic tractor steering would help direct the fertilizer to the root zone only
Summary – VRF Technology

- Variable rate fertilization is a cost-effective technology with immediate benefits for conserving nutrients in horticultural crops; nutrient loading per cropped acre is reduced.

- Fertilization of bare uncropped soil is always avoided with VRF, but accurate data for variable rates in different soil and crop conditions is often lacking.

- Different horticultural crops need VRF systems adapted to their particular production systems. Research is needed to develop the best VRF systems for accurate fertilizer rates and placement.