Background

- Federal Clean Water Act (FCWA), 1972
- Total Maximum Daily Loads (TMDLs)
  - Best Management Practices (BMPs)
- FDACS Vegetable and Row Crop BMP Manual
- Numerous BMPs listed but few have been verified
- Irrigation and nutrient management BMPs
  - Soil moisture based irrigation
  - Using recommended fertilizer
- Majority of tomato and watermelon growers in south Florida growers use seepage irrigation
- Need to evaluate the irrigation and nutrient BMPs
Best Management Practices (BMP)

“BMPs are a practice or combination of practices determined by the coordinating agencies, based on research, field-testing, and expert review, to be the most effective and practicable on-location means, including economic and technological considerations, for improving water quality in agricultural and urban discharges.”

Florida Department of Agriculture and Consumer Services (FDACS)
Majority of South Florida Vegetable Crop Produced with Seepage Irrigation
Typical Studies Related to BMP

- Typical BMP studies
  - Evaluate crop yield or water quality,
  - Conducted on small scale plots
  - Confounding water quality effects due to groundwater mixing

- Lack of **Systems Approach**
  - Yield
  - Water use and quality
  - Economics
Objective

Evaluate the effectiveness of irrigation and nutrient BMPs for seepage irrigated tomato-watermelon production system for yield, water use, water quality, and farm income

Field Area – 3.6 acres
  • Six 0.6 ac fields

Crops
  • Watermelon (2 Spring seasons)
  • Tomato (4 seasons)

Hydrologically Isolated plots

Three treatments:
  • Industry fertilizer-water input (High Rate, HR) - Grower Survey
  • BMP fertilizer-water input (BMP Recommended Rate, RR)
  • BMP input with sub-surface drip (RR-SD) - Survey
## Irrigation and Nutrient Treatments

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Watermelon</th>
<th>Tomato</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N  lb/ac</td>
<td>P2O5 lb/ac</td>
</tr>
<tr>
<td>HR</td>
<td>265</td>
<td>170</td>
</tr>
<tr>
<td>RR &amp; RR-SD</td>
<td>150 Soil Test</td>
<td>Soil Test</td>
</tr>
</tbody>
</table>
Measurements

- **Fruit yield**
  - 2-3 harvests

- **Plant nutrients** (N and P)
  - Leaf tissue
  - Whole plant

- **Hydrology**
  - Water use
  - Soil moisture
  - Water table depth

- **Soil and Water quality (NO3, TN, TP)**
  - Soil (0-10, 10-20, 20-30, 30-40 cm)
  - Shallow and deep groundwater (N and P)
Results
- Average annual rainfall ≈ 54 inch
- Rainfall from Hurricane Wilma (October 24th 2005) ≈ 8 inch.
Yield
# Tomato Yield

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Yield (box/ac)</th>
<th>Treatment</th>
<th>Yield (box/ac)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fall 2004</strong></td>
<td></td>
<td><strong>Fall 2005</strong></td>
<td></td>
</tr>
<tr>
<td>HR</td>
<td>1,885</td>
<td>HR</td>
<td>3,224</td>
</tr>
<tr>
<td>RR</td>
<td>1,815</td>
<td>RR</td>
<td>2,635</td>
</tr>
<tr>
<td>RR-SD</td>
<td>1,946</td>
<td>RR-SD</td>
<td>2,592</td>
</tr>
<tr>
<td><strong>Fall 2006</strong></td>
<td></td>
<td><strong>Spring 2006</strong></td>
<td></td>
</tr>
<tr>
<td>HR</td>
<td>659</td>
<td>HR</td>
<td>2,449</td>
</tr>
<tr>
<td>RR</td>
<td>853</td>
<td>RR</td>
<td>2,089</td>
</tr>
<tr>
<td>RR-SD</td>
<td>849</td>
<td>RR-SD</td>
<td>2,088</td>
</tr>
</tbody>
</table>

No statistical difference detected
# Watermelon Yield

<table>
<thead>
<tr>
<th>Year</th>
<th>Treatment</th>
<th>Yield (cwt/ac)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Diploid</td>
<td>Triploid</td>
</tr>
<tr>
<td>2004</td>
<td>HR</td>
<td>758a</td>
<td>444a</td>
</tr>
<tr>
<td></td>
<td>RR</td>
<td>538a</td>
<td>261a</td>
</tr>
<tr>
<td></td>
<td>RR-SD</td>
<td>475a</td>
<td>349a</td>
</tr>
<tr>
<td>2005</td>
<td>HR</td>
<td>--</td>
<td>345a</td>
</tr>
<tr>
<td></td>
<td>RR</td>
<td>--</td>
<td>193b</td>
</tr>
<tr>
<td></td>
<td>RR-SD</td>
<td>--</td>
<td>214b</td>
</tr>
</tbody>
</table>

Treatment effect detected for yield during 2005
Watermelon
Tissue and Petiole Sap – Spring 2005

Leaching rainfall event: 3 in. over 3 days or 4 in. over 7 days
Water Table Depth and Soil Moisture

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Water Table</th>
<th>Soil Moisture</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR</td>
<td>21</td>
<td>19</td>
</tr>
<tr>
<td>RR</td>
<td>22</td>
<td>14</td>
</tr>
<tr>
<td>RR-SD</td>
<td>23</td>
<td>17</td>
</tr>
</tbody>
</table>
Average Water Use

**Tomato**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Water Use (inch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR</td>
<td>63</td>
</tr>
<tr>
<td>RR</td>
<td>58</td>
</tr>
<tr>
<td>RR-SD</td>
<td>27</td>
</tr>
</tbody>
</table>

System: HR – 74 in, RR – 68 in, RR-SD – 37 in
Soil and Groundwater Quality
Soil N (Tomato)

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Treatment &amp; Significance</th>
<th>Root Zone (0-8 in)</th>
<th>Below Root Zone (8-16 in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO₃-N (mg/kg)</td>
<td>HR</td>
<td>121</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>RR</td>
<td>63</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>$P$ - value</td>
<td>$&lt; 0.05$</td>
<td>0.07</td>
</tr>
<tr>
<td>TN (mg/kg)</td>
<td>HR</td>
<td>519</td>
<td>269</td>
</tr>
<tr>
<td></td>
<td>RR</td>
<td>363</td>
<td>230</td>
</tr>
<tr>
<td></td>
<td>$P$ - value</td>
<td>$&lt; 0.05$</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Treatment effect ($P<0.05$) occurred mostly within the crop bed
Groundwater N

Average NOx-N, NH3-N and TKN within shallow groundwater for plot 1 during period of record

<table>
<thead>
<tr>
<th>Date</th>
<th>Avg TKN</th>
<th>Avg NH3N</th>
<th>Avg NOxN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oct-03</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apr-04</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sep-04</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feb-05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jul-05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jan-06</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jun-06</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nov-06</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apr-07</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Groundwater N

Average NOx-N, NH3-N and TKN within shallow groundwater for plot 3 during the period of record

<table>
<thead>
<tr>
<th>Date</th>
<th>Avg TKN</th>
<th>Avg NH3N</th>
<th>Avg NOxN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oct-03</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apr-04</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sep-04</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feb-05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jul-05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jan-06</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jun-06</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nov-06</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apr-07</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

High rate (HR)

Recommended rate (RR)
Groundwater Total P

Average TP within shallow groundwater for plot 3 during the period of record

<table>
<thead>
<tr>
<th>Date</th>
<th>Concentration (μg/L)</th>
<th>Avg TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan-04</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Aug-04</td>
<td>5000</td>
<td></td>
</tr>
<tr>
<td>Feb-05</td>
<td>10000</td>
<td></td>
</tr>
<tr>
<td>Sep-05</td>
<td>15000</td>
<td></td>
</tr>
<tr>
<td>Mar-06</td>
<td>20000</td>
<td></td>
</tr>
<tr>
<td>Oct-06</td>
<td>25000</td>
<td></td>
</tr>
<tr>
<td>Apr-07</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

High rate (HR)

Recommended rate (RR)
Treatment effect detected ($P < 0.05$) for shallow groundwater N and P
No treatment effect detected \((P < 0.05)\) for deep groundwater N and P
So is RR a BMP?

Long-term study
Summary

- No statistical difference in tomato yield between Industry and BMP
- Under “average” rainfall conditions, no statistical difference in watermelon yield between Industry and BMP
- Wetter conditions during the spring season may reduce the watermelon yield. Further research is needed to develop nutrient management strategies (especially K) for wetter conditions.
Summary

- The BMPs reduced the total N and P concentrations in groundwater by 50 and 33%, respectively compared to the Industry.
- The BMPs reduced the water use by 7% (seepage, RR) and 50% (sub-drip, RR-SD)
- Long-term studies needed to detect the differences in tomato yield, if present.
- Reduced N and P leaching to the groundwater found in this study is likely to reduce the N and P loads.
- First study to quantify yield, economic, and water quality effects of BMPs, more needed
Acknowledgements

Southwest Florida Vegetable Growers Research Fund

Vegetable Growers
Rainfall during spring 2005 (18.2 in) was 3 times greater than spring 2004 (5.4 in).

Seasonal average = 11.1 in.

* Beds preparation and transplant - 2/21/05
Summary

- No yield differences for tomato yield
- No yield differences for watermelon produced under average weather conditions
- N-Leaching higher and more frequent in the HR treatment
- Higher concentrations of groundwater N and P are maintained above the spodic layer of the HR treatment
- No treatment effect detected in groundwater N and P below the spodic layer
Conclusions

- RR-SD treatment reduced water use by more than 50% compared to HR and RR treatments.
- RR and RR-SD treatments is a BMP under average weather conditions.
- First ever study to show a link between recommended fertilizer-water inputs and improved groundwater quality with no effect on yield.
Study Implications

- First ever study to show a link between recommended fertilizer-water inputs and improved groundwater quality with no effect on yield.
- Growers maybe more receptive in accepting and adopting recommended fertilizer-water inputs for vegetable production in south west Florida.
Background

- Cash value* – $140,392,000
- Yield* – 330 cwt/ac.
- Harvested acreage* – 26,100 ac.
- Plastic mulched beds
- Crop rotation
  - Watermelon-Spring
  - Tomato or pepper-Fall
- Florida irrigation systems (vegetable crops)
  - Sprinkler(69,951 ac.)†
  - Micro (21,025 ac.)†
  - Flood (118,949 ac.)†

* (USDA, 2008), †(Marella, 2004)
Drip vs. Seepage Irrigation

**Drip**
- Water and fertilizer (Can apply as needed)

**Seepage**
- Water (All fertilizer - pre-plant)

Image source: www.jains.com/irrigation
Recommended BMPs

- Nutrient management
  - Optimum N rates
  - Soil test based P and K applications
  - Supplemental (N and K)
    - Hand/Liquid fertilizer injection wheel
    - Extended harvest season
    - Open field leaching Rainfall-3” in 3 days, 4” in 7 days

- Water management
  - Soil moisture-based (Seepage and Drip)
  - ET-based (Drip)

Image source: The Vegetarian Newsletter (www.hos.ufl.edu/vegetarian/)
Current Practice (grower survey)

- Nutrient Input
  - Likely greater than recommended
  - Applied as insurance to ensure max yield
    - Multiple harvests
    - Healthier plants
  - Limited use of soil test based P and K
- Water management
  - Moisture content above field capacity
  - Limited use of soil moisture or ET-based irrigation management

Image source: www.musicpodcasting.org/home/node/48
### Watermelon Grower Survey

<table>
<thead>
<tr>
<th>South Florida*</th>
<th>N (lbs/ac)</th>
<th>P$_2$O$_5$ (lbs/ac)</th>
<th>K$_2$O (lbs/ac)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>199 (150)</td>
<td>128 (120-L)</td>
<td>347 (120-L)</td>
</tr>
<tr>
<td>Min</td>
<td>138</td>
<td>83</td>
<td>220</td>
</tr>
<tr>
<td>Max</td>
<td>266</td>
<td>220</td>
<td>501</td>
</tr>
</tbody>
</table>

L = soil testing low nutrient, *(Shukla et. al., 2004)

- Growers apprehensive about nutrient recommendations
- Data needed to evaluate if water-nutrient BMPs work wrt yield and water quality
- Focus on a specific nutrient BMP may detract growers from other BMPs
- When a management practice becomes a **BMP**?
BMP Essentials

- Improve water quality in agricultural discharges
- Include economic and technological considerations

BMP Effectiveness study must address:

- Water quality
- Crop yield
- Farm economics
Watermelon-Tomato BMP Study*

- Watermelon-Tomato rotations
- Traditional cultural practices
- Grower average (HR) Vs. recommended (RR) nutrient-water rates
- Plots hydrologically separated - reduces uncertainty groundwater quality analysis.
- Crop yield and groundwater quality evaluated

(Shukla and Hendricks, 2009)
Results

- Yield Analysis
- Tissue Analysis
- Economic Analysis
- Groundwater Quality Analysis
- Water Use

Source: infinitibusinesssolution.com
Watermelon Yield

<table>
<thead>
<tr>
<th>Year</th>
<th>Treatment</th>
<th>Triploid Yield (cwt/ac.)</th>
<th>Significance</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>HR</td>
<td>444</td>
<td></td>
<td>0.336</td>
</tr>
<tr>
<td></td>
<td>RR</td>
<td>261</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>RR-S</td>
<td>349</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>HR</td>
<td>345</td>
<td></td>
<td>0.031</td>
</tr>
<tr>
<td></td>
<td>RR</td>
<td>193</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>RR-S</td>
<td>214</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Yield reduction occurred during 2005. Why?
Leaf Tissue Analysis

- Watermelon plants in RR treatments deficient in Potassium (and N?)
- Potassium deficiency likely due to leaching rainfall event
- Economic impact?

Hendricks, Shukla, Cushman, Obreza. Roka, McAvoy, Dash lines- RR and RR-SD and Portier 2007
Economic Analysis (Year 2005)

- Added yield from HR
  I. Low – 130 cwt/acre
  II. High – 150 cwt/acre
- Average season prices for triploids
  a. $8.40/cwt in 2004 to
  b. $15.50/cwt in 2005
- HR Return Gain (low yield gain and market price) = $590/acre
- HR Return Gain (high yield gain and market price) = $1764/acre

Environmental Impact?  
Hendricks et al (2009)
Groundwater Quality (N Conc):

Avg TKN, NH3-N and NOx-N within RR and HR treatments

- Integrated systems approach used to analyze groundwater quality
- Watermelon and tomato rotation
Soil and Groundwater Quality

- Soil Solution N Conc$^n$
  HR > RR and RR-SD
- Improved groundwater quality with RR and RR-SD
- Quality of deep groundwater unchanged

**Graphs:**
- NOx-N (mg/L) and TN (mg/L) concentrations in soil solution, shallow groundwater, and deep groundwater.

**Bar Charts:**
- TP (ug/L) concentrations in shallow and deep groundwater.
Shallow Groundwater P (above spodic)

Progressive Accumulation of P

Average TP Conc. in HR 47% higher than average TP Conc. in RR
Water Use

- Reduced average water use for RR and RR-SD compared to HR

![Bar chart showing water use comparison between HR and RR treatments. The bar for HR is labeled 187 cm, and the bar for RR is labeled 133 cm.]
So, was it a BMP?

Water-nutrient BMP status for watermelon Yield

- RRs worked under “average” weather conditions
- RRs reduced the yield and profit under “wet” conditions
- RRs improved water quality-groundwater (and surface water)
Drip Irrigation

- ET-based water management for watermelon
- Crop Coefficient (Kc)
  - 0-28 DAT – 0.57
  - 29-56 DAT – 0.89
  - 57-84 DAT – 0.76
Future Research Issues

- The BMP evaluation study needs to be continued for more growing seasons to better evaluate BMP effectiveness under variable weather and economic condition
- Development of water table management tools
  - Water table vs rainfall relationship for active water table management for irrigation and drainage
  - Linking rainfall predictions with water and nutrient input
Future Research Issues

- Leaching rainfall
  - evaluation of supplemental fertilizer
  - frequent “normal” rainfall vs. “leaching rainfall”
    - water table change = 16 x rain (Jaber and Shukla, 2006)
- Comparison of drip and seepage production systems
  - water quality, yield, and economic
  - variable soil conditions
- Drip irrigation management
  - not managed properly, can have higher leaching than seepage
  - ET-based using recently developed Kc
  - water quality effectiveness
- How to minimize leaching after removing plastic
  - considerable N-P-K left after harvest