Novel Growth Substrates and Smart Irrigation Strategies to Reduce Water Consumption of Arizona’s Greenhouse Industry

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Outline

- Arizona Water Issues
- Methods
- Key Findings
- Conclusions
Arizona Water Use and Demand

Agriculture, 5613800, 75%
Municipal, 1495300, 20%
Industrial, 403100, 5%
Effluent, 2513, 3%
Groundwater, 39733, 43%
Surface, 50032, 54%

Source: Arizona Water Atlas, Arizona Department of Water Resources, September 2010
Arizona Water Use and Demand

Left Graphs Source: http://www.westernresourceadvocates.org/azmeter/singlefamuse.gif
Right Graph Source: Sensus 2010
Water Savings

The problematic in water savings is an issue to be solved by a group of interdisciplinary researchers including:

- Plant breeders
- Biotechnology
- Ecologist
- Agronomist
- Engineers
Arizona’s Greenhouse Industry

- 130 ha
- Year round crop
- 75 kg/m²/year
- 800 workers
- 10x less water
- Changing from rockwool to coconut coir

Eurofresh Farms, Willcox, AZ
Conventional Irrigation

Left picture source: http://www.desertrootsfarm.com/pictures/tomatoes.jpg
Right picture source: http://www.rwandaworks.com/useruploads/images/GREEN%20HOUSE%20INYANYA%20%284%29.jpg
Greenhouse Irrigation
Why Greenhouses?

- Do not depend on outside climate
- Use of unproductive land
- Better use of resources (water, energy, space, capital and labor)
- Crop production year round
- Better control over pest and diseases
- Year round jobs
- Higher yield and quality than field
Why Growth Media?

- Better irrigation control
- Easy to manipulate salt content and pH because of limited volume
- Control of soilborne pathogens and weeds
- Consistent medium properties
- Characteristics can be adjusted for specific crop

Important characteristics:

- The use soil fumigants like methyl bromide
- Agriculture can be done in locations where soils are poor in nutrients
Growth Media

- Foamed glass aggregates
- Foamed glass aggregates and coconut coir
- Rockwool
- PE-PET fibers
- Coconut coir
- Perlite
Irrigation Scheduling Methods

- Lysimeters
- Evapotranspiration (crop coefficient)
- Drainage percentage
- Light based
- Electromagnetic sensors
- Matric potential sensors
Media Characterization

- **Soil Water Characteristic Curve**
  - Water retained in the growing media at certain suction (Matric Potential)

- **Available Water Content and Integral Energy**

- **Saturated Hydraulic Conductivity**

- **Bulk Density**

- **Surface Area**

- **Particle Density**
Soil Water Characteristic Curve

\[ \Theta = \frac{\theta - \theta_r}{\theta_s - \theta_r} = \left[ \frac{1}{1 + (\alpha|h|^n)} \right]^m \]

Van Genuchten, 1980

\[ \Theta = \frac{\theta - \theta_r}{\theta_s - \theta_r} = w_1 \left[ \frac{1}{1 + (\alpha_1|h|^{n_1})} \right]^{m_1} + w_2 \left[ \frac{1}{1 + (\alpha_2|h|^{n_2})} \right]^{m_2} \]

Durner, 1994

Average Water Content and Integral Energy

\[ W_I(\psi_i, \psi_f) = \frac{1}{|\psi_i - \psi_f|} \int_{\psi_f}^{\psi_i} \left( \theta_r + (\theta_s - \theta_r) \left[ \frac{1}{1 + (\alpha|\psi|^{n})} \right]^m \right) d\psi \]

\[ W_I(\psi_i, \psi_f) = \frac{1}{|\psi_i - \psi_f|} \int_{\psi_f}^{\psi_i} \left( \theta_r + (\theta_s - \theta_r) \left( w \left[ \frac{1}{1 + (\alpha_1|\psi|^{n_1})} \right]^{m_1} + (1 - w) \left[ \frac{1}{1 + (\alpha_2|\psi|^{n_2})} \right]^{m_2} \right) \right) d\psi \]
<table>
<thead>
<tr>
<th>Property</th>
<th>Rockwool</th>
<th>PET Fibers</th>
<th>Coco Coir</th>
<th>Perlite</th>
<th>Foamed Glass</th>
<th>FG &amp; Coco Coir</th>
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</thead>
<tbody>
<tr>
<td>$\theta_s$ (m$^3$ m$^{-3}$)</td>
<td>0.94</td>
<td>0.77</td>
<td>0.84</td>
<td>0.68</td>
<td>0.92</td>
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<td>$\theta_r$ (m$^3$ m$^{-3}$)</td>
<td>0.008</td>
<td>0.005</td>
<td>0.01</td>
<td>0.001</td>
<td>0.013</td>
<td>0.001</td>
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<td>$\alpha$ (kg J$^{-1}$)</td>
<td>0.80</td>
<td>0.84</td>
<td>0.18</td>
<td>0.52</td>
<td>2.83</td>
<td>0.001</td>
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<td>$n$</td>
<td>3.76</td>
<td>3.39</td>
<td>1.39</td>
<td>1.40</td>
<td>1.56</td>
<td>1.99</td>
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<td>$\alpha_1$ (kg J$^{-1}$)</td>
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<td>-</td>
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<td>1.43</td>
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<tr>
<td>$w$</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>0.53</td>
<td>0.68</td>
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<td>$\theta_{0.8}$ (m$^3$ m$^{-3}$)</td>
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<td>0.67</td>
<td>0.83</td>
<td>0.63</td>
<td>0.26</td>
<td>0.51</td>
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<td>$\theta_{50}$ (m$^3$ m$^{-3}$)</td>
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<td>0.005</td>
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<td>0.04</td>
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<td>$\theta_{10}$ (m$^3$ m$^{-3}$)</td>
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<td>0.01</td>
<td>0.61</td>
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<td>0.08</td>
<td>0.25</td>
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<td>$\theta_{1500}$ (m$^3$ m$^{-3}$)</td>
<td>0.008</td>
<td>0.005</td>
<td>0.10</td>
<td>0.05</td>
<td>0.017</td>
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<td>$W_{l(0.8-50)}$</td>
<td>0.03</td>
<td>0.02</td>
<td>0.49</td>
<td>0.27</td>
<td>0.06</td>
<td>0.24</td>
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<td>$E_{l(0.8-50)}$</td>
<td>2</td>
<td>2</td>
<td>15</td>
<td>11</td>
<td>6</td>
<td>4</td>
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<tr>
<td>$W_{l(10-1500)}$</td>
<td>0.008</td>
<td>0.005</td>
<td>0.155</td>
<td>0.075</td>
<td>0.021</td>
<td>0.197</td>
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<tr>
<td>$E_{l(10-1500)}$</td>
<td>16</td>
<td>17</td>
<td>166</td>
<td>151</td>
<td>109</td>
<td>580</td>
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Laboratory Experiment

Materials

- 6 Rockwool blocks
- Foamed glass aggregates (<1.27 cm)
  - Why foamed glass?
- 3 Foamed glass block
- 3 Tensiometer (porous cap, metal shaft and transducer)
- 2 Load cells
- Flow meter
- Solenoid valve
Experiment Measurements

- **Datalogger, collected every minute:**
  - Matric potential
  - Temperature
  - Water flow
  - Box weight
  - Drainage weight

- **Irrigation**
  - 9:00 to 17:00
  - 2 min on and 14 min off
  - Drip flow 33 cm³/min
  - 6 drip emitters
Laboratory Experiments
HYDRUS 3D Numerical Simulations

- HYDRUS 3D is a software package for simulating water, heat, and solute movement in two- and three-dimensional variably saturated media.

- Solves the Richards equation for saturated and unsaturated flow. It incorporates a sink term to account for water uptake by plant roots.

- It is used to analyze water and solute movement in partially or fully saturated porous media.
Growth Media for HYDRUS 3D

The graph shows the matric potential (m) against volumetric water content ($m^3/m^3$) for different media types:
- Foam Glass Agg.
- Foamed Glass Block
- Rockwool

The graph indicates the water content and matric potential relationship for these media, with different curves representing each type.
HYDRUS 3D Simulations
Key Findings

- We can use tensiometers to schedule irrigation in foamed glass
- Water fluxes can be well simulated with HYDRUS 3D and utilized for optimization of irrigation scheduling.
  - Minimize water and fertilizer loss
  - Increase water use efficiency
  - Avoid water or oxygen stress
Key Findings

- Tensiometers can be used to trigger irrigation when the matric potential is close to the threshold for plant stress.

- Irrigation of greenhouse substrates can be directly based on the SWCC of the growth medium with the use of matric potential thresholds, not on environmental conditions.

- Based on the average water content and the Integral Energy of the growth medium we can pick the best substrate for an specific crop.
Conclusion

Numerical simulations in conjunction with sensor based irrigation can be utilized to increase water use efficiency by decreasing drainage while providing a stress-free growth environment ensuring high yields and high quality products.

A way to save water in Arizona is by optimizing irrigation. This research gives insight in how to manage irrigation scheduling in greenhouse agriculture.

As final though in Arizona there is a need to change some parts with conventional agriculture to greenhouse agriculture. Arizona offers 350 day of sunlight and the solar radiation is higher than northern parts of the US.
Thank you
Acknowledgment

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