Learning to listen to plants

—

tools for efficient water use

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organism-as-sensor
The neglected eukaryote

water stress?
nitrogen status?
root architecture?
microbiome?
stomatal regulation?
metabolic rates?
hormone signals?
...

(Stroock et al., ARFM, 2014)

(Gray’s Anatomy, 1858)
Water stress controls biology...

**GROWTH**

[wonderopolis.org](http://wonderopolis.org)

**QUALITY**

[bamag solutions.com](http://bamag solutions.com)

**YIELD**

[starkbros.com](http://starkbros.com)

**DISEASE**

[phys.org](http://phys.org)
Water stress is increasing

**Oct. 2014**
*U.S. Drought Monitor*

**California**

**Sept. 2016**

**Drought Severity**
- Abnormally dry
- Moderate drought
- Severe drought
- Extreme drought

**Rainfed crop yield loss**

<table>
<thead>
<tr>
<th>Region</th>
<th>Fruit% loss</th>
<th># fruit farms</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>13%</td>
<td>2</td>
</tr>
<tr>
<td>II</td>
<td>20%</td>
<td>5</td>
</tr>
<tr>
<td>III</td>
<td>75%</td>
<td>4</td>
</tr>
<tr>
<td>IV</td>
<td>79%</td>
<td>5</td>
</tr>
<tr>
<td>V</td>
<td>30%</td>
<td>4</td>
</tr>
<tr>
<td>VI</td>
<td>33%</td>
<td>43</td>
</tr>
<tr>
<td>VII</td>
<td>69%</td>
<td>14</td>
</tr>
<tr>
<td>VIII</td>
<td>60%</td>
<td>2</td>
</tr>
</tbody>
</table>

Mean% loss 47%
Total # farms 79

**Irrigated crop yield loss**

<table>
<thead>
<tr>
<th>Region</th>
<th>Fruit% loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0%</td>
</tr>
<tr>
<td>II</td>
<td>4%</td>
</tr>
<tr>
<td>III</td>
<td>14%</td>
</tr>
<tr>
<td>IV</td>
<td>13%</td>
</tr>
<tr>
<td>V</td>
<td>4%</td>
</tr>
<tr>
<td>VI</td>
<td>14%</td>
</tr>
<tr>
<td>VII</td>
<td>15%</td>
</tr>
<tr>
<td>VIII</td>
<td>25%</td>
</tr>
</tbody>
</table>

Mean% loss 11%
Total # farms

(Sweet et al., Ag Forest Meteor, 2017)
Water stress is *not* controlled

40% of all food crops are irrigated

irrigation accounts for 70% of human use of fresh water.

typical irrigation provides 200% of water needed by crop

*(Fereres and Soriano, 2007; United Nations, 2012)*

1 almond 1.1 gallon water

(Mother Jones)
State-of-the-art

Schölander Pressure Chamber (1965)
stress = tension = *negative* pressure
stress = tension = negative pressure
synthetic plants?

synthetic plants vs. plants

-220 atm

C. Tuberculata (warty zieria)

(Larter et al., Plant Phys, 2016)

(Schöander et al., Science (1965))

synthetic plants - development


“μTensiometer”

Alan Lakso  Vinay Pagay  Michael Santiago  Siyu Zhu  Winston Black
synthetic plants ↔ real plants

Grape
(Matchbook Wines; Zamora, CA)

Almond
(Done-Again Farm; Arbuckle, CA)

Apple
(Cornell Orchards; Ithaca, NY)

Corn
(Musgrave Farms; Auburn, NY)

\[ \Psi_{stem} \]

stem (trunk)

xylem

μTensiometer

STRESS!
almonds

John Monroe
Done Again Farm - Arbuckle, CA
Blue Diamond Growers Board

2015

(Lucy Nicholson/Reuters)
almonds – dynamical system

John Monroe
almonds – under sampled

summer 2017

irrigation
almonds – connecting the dots

Done-Again Farm, Arbuckle, CA

microTensiometer

irrigation

OVER IRRIGATED

OPTIMAL

STRESSED

Michael Santiago

FloraPulse
irrigation

1 CO₂
100’s H₂O

→ properties of soil, roots, trunk, stomates, canopy,...
almonds – resolving the dynamics

weather (environment)
dynamics

model (physiology)

Siyu Zhu
Kathryn Haldeman
almonds – resolving the dynamics

weather (environment)

model (physiology)

dynamics

Siyu Zhu
Kathryn Haldeman
almonds – resolving the dynamics

weather (environment)

model (physiology)

dynamics
almonds – closing the loop

→ Process Optimized Water Management
(efficiency, yield, quality, labor, profit, environment,...)

(Sheng et al., arXiv, 2018)
almonds – supporting good management

(Cornell/USDA/UC Davis/WSU)
models

organism-as-sensor

systems

organism-as-sensor

satellite/drone + organism-as-sensor + cloud + farmer/scientist

data digital twin

decision support optimization discovery
Thank you.