



SCRI - CLEAN WATER³
REDUCE, REMEDIATE, RECYCLE

New tools for old problems

Irrigation Management Using Soil Moisture Sensors



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Smart Farms



SCRI-MINDS—Managing Irrigation and Nutrition via Distributed Sensing

saving water increasing efficiency reducing environmental impacts



United States
Department of
Agriculture

National Institute
of Food
and Agriculture

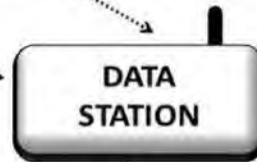
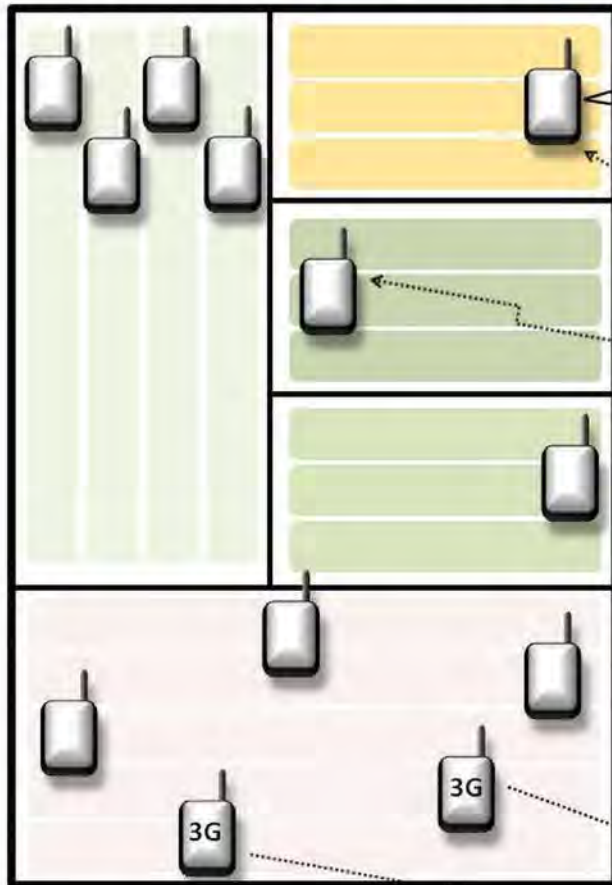
USDA-NIFA-SCRI Award no. 2009-51181-05768

Our New Tools and Methods

1. Sensor Networks – ground and cloud-based systems
2. “Our Toolbox”
3. Software Development – Translating Information into Decisions
 - *Automated Irrigation Control*
 - *Model Integration*
 - *Alert Capabilities*
4. Economic Impacts – Multiple and Synergistic

Sensor Networks

Production Area / Irrigation Zone



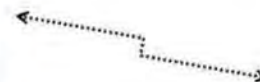
Local
Computer

Grower Input

(Via Secure Internet Connection)



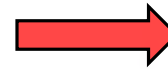
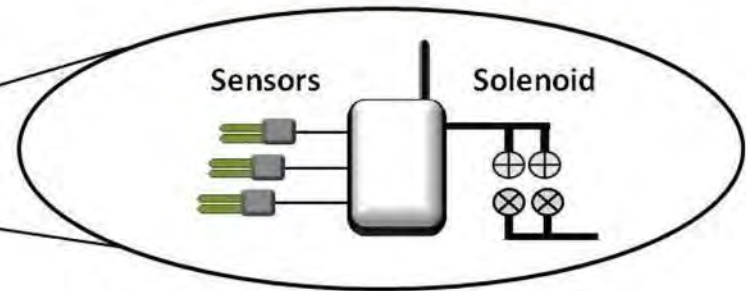
Remote
Server



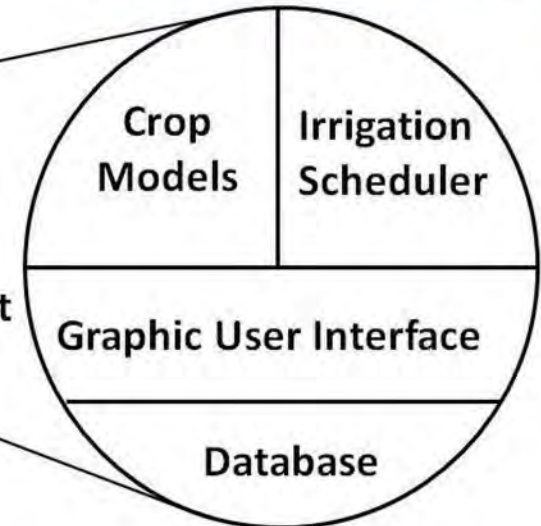
Smartphone or
Handheld Device



Local Irrigation Control



Global Irrigation Control



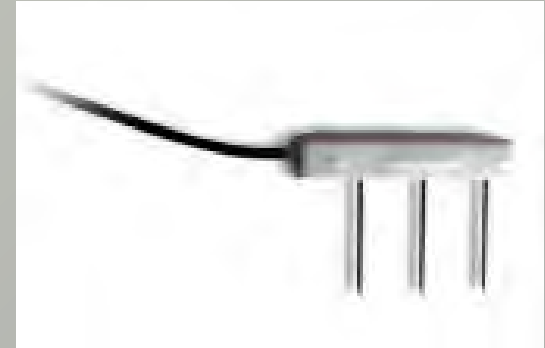
Smart Toolbox



Soil Moisture, EC Sensors



Various soil moisture sensors



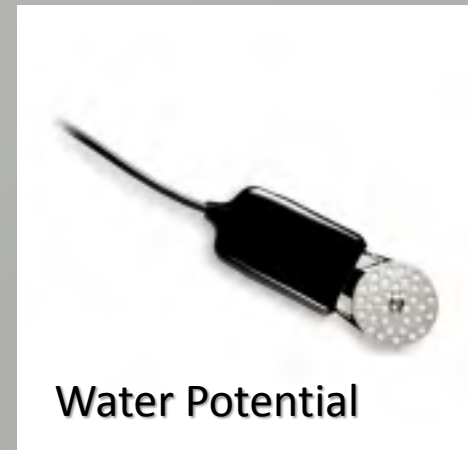
GS3: EC, soil moisture,
soil temperature



Line pressure



In-line/Tank EC



Water Potential

Environmental Sensors



Photosynthetic
and Total radiation



Wind speed
and direction



Precipitation



temperature, RH
and VPD



Sonic anemometer



Leaf wetness, Dew and Ice

Radio Dataloggers



Monitoring
Node



Control
Node



Cellular (3G)
Monitoring Node

Automated Control Capability

- Developed an advanced node, capable of controlling irrigation and reading multiple sensors
- Data is used by growers in real-time to make decisions and monitor crop/field conditions
- Plant irrigation can be determined automatically based on set-points or using plant water use models
- Sensor data and irrigation control can be accessed remotely
- System is fault-tolerant and reliable



PLANTPOINT
Component Specifications

For More Information:
ALAN@POINT@CROTON.COM
(800) 352-2758

MONITOR NODE	CONTROL NODE	SOFTWARE
<p>4800</p> <p>5 sensor ports</p> <p>Supports a variety of Onsen Sensors</p> <ul style="list-style-type: none"> Soil moisture sensor Soil water potential Soil salinity Flow sensor <p>900 MHz ISM license-free Radio Technology</p> <ul style="list-style-type: none"> 2.3 mile communication range with Gateway 800 MHz ISM license-free radio technology 1000m (3300 ft) <p>Configurable through SmartBase</p> <p>Powered by 5 AA batteries</p>	<p>4800</p> <p>2 sensor ports</p> <p>For the sensor, external connectivity (e.g., relay, pump, fan, valve, etc.)</p> <ul style="list-style-type: none"> Relay available in up to 24V AC (24V AC) and DC having various (DC) DC Relay control or pump control (if not pump) <p>Relay time-based watering schedule</p> <p>900 MHz ISM license-free Radio Technology</p> <ul style="list-style-type: none"> 2.3 mile communication range with Gateway 800 MHz ISM license-free radio technology 1000m (3300 ft) <p>Configurable through SmartBase</p> <p>Powered by 5 AA batteries with 24V AC charger (24V AC) or solar charger (24V DC)</p>	<p>Simply intuitive graphical user interface optimized for commercial users</p> <p>Outbreaks with "In-A-Click" data summary and alerts</p> <p>Set point control using multiple variables:</p> <ul style="list-style-type: none"> Weather sensor Soil water potential Soil salinity Soil moisture <p>Allows multiple channel control protocols</p> <p>User interface</p> <p>Integration decision support tools</p> <p>Real-time control via</p> <p>Web interface for PCs, smartphones, and tablets with on-site and remote access</p>

GATEWAY	SMARTBASE
<p>Links Monitoring and Control Nodes with SmartBase & local area network</p> <p>120 meter short communication range with SmartBase</p> <p>Not in use otherwise</p> <p>No configuration necessary</p> <p>Also configurable</p> <p>Power and communication over one wire</p> <p>Not</p>	<p>Industrial computer with single display running PlantPoint software</p> <p>No moving parts and wide temperature range tolerance</p> <p>Reliable weather functionality with auto restart</p> <p>VPN enabled for remote access and troubleshooting</p>

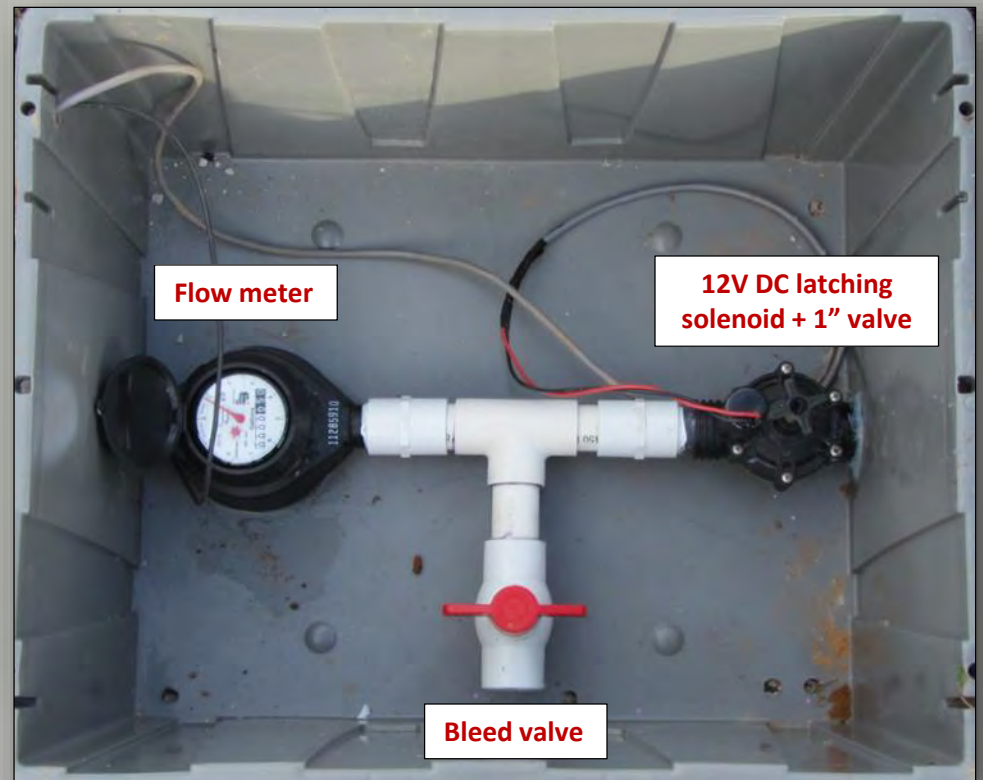
(Data collected with the PlantPoint system displayed in operational greenhouses and commercial farms shows, on average, a 10% reduction in applied water, a 20% reduction in nitrogen use, reduced disease losses, and better production times. For more information on these studies, please visit: CROTON.COM/EDUCATION/PLANTPOINT

Kohanbash, Kantor, Martin and Crawford, 2013
HortTechnology 23: 725-734

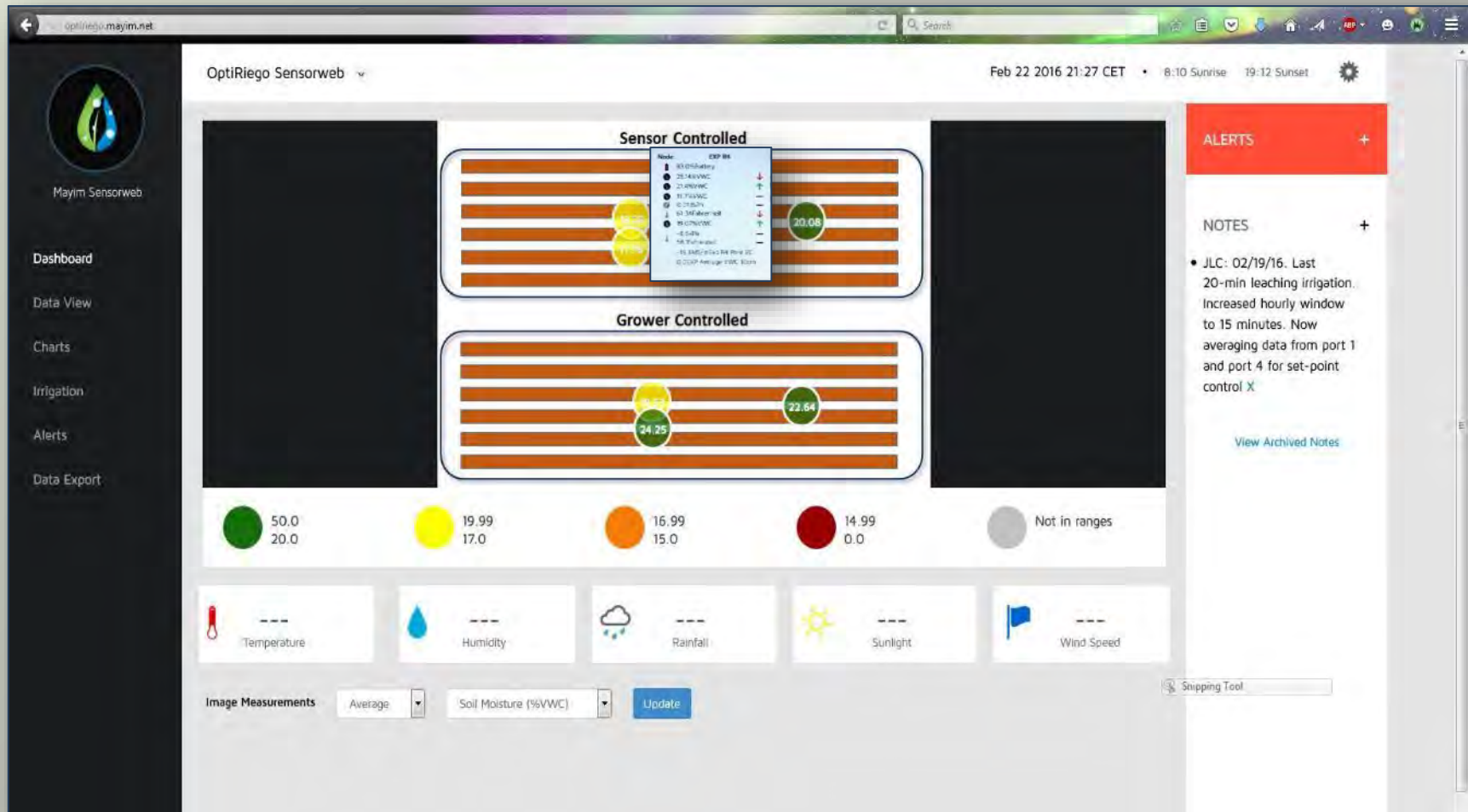
Set-Point Irrigation Scheduling



- ✓ Prototype nR5-DC Node – Integrated with a flow meter and controls a 12V latching solenoid
- ✓ **Allows us to control and measure water applications in remote locations where there is *NO* electrical power**



SensorWeb™ Software Interface



Farm (website) Homepage – “Management at a Glance”

SensorWeb Micro-Pulse Irrigation Scheduling Capability

The screenshot displays the OptiRiego Sensorweb web interface. The left sidebar contains navigation links: Dashboard, Data View, Charts, Irrigation, Alerts, and Data Export. The main content area is titled 'OptiRiego Sensorweb' and shows a 'Sensor Controlled' and 'Grower Controlled' irrigation status. A table on the right lists various pulse types and their durations. Below the table, a graph shows the pulse duration over time, with a red circle highlighting the 'Edit' button. The bottom section shows a timeline for scheduling irrigation events, with a 'submit' button and a 'Send Manual Irrigation Command' link.

Name	Pulse Duration(s)	Time Between Pulses(s)	Number of Pulse Cycles	Total Time of Event
Standard Single Pulse	200	0	1	200
Cycle MicroPulse	30	30	3	300
Standard Double Pulse	20	130	2	300
Micropulse 30	30	270	1	300
Micropulse 60	60	240	1	300
Micropulse 90	90	210	1	300
Micropulse 120	120	180	1	300
Double Micropulse 60	60	90	2	300
UNKNOWN TYPE	10	250	1	260
Micropulse 240	240	60	1	300

Name: MicroPulse 240

Pulse Duration(s): 240

Irrigation On: [Graph showing pulse duration over time]

Irrigation Off: [Graph showing pulse duration over time]

Time Between Pulses(s): 60

Number of Pulses: 1

Update current pulse type | Save as new pulse type | Delete current pulse type

Add Scheduled Event

Select Irrigation Node/Group: Exp_Control | Configure Irrigation Groups

Select Irrigation Control Source: Sensors on the Node | Low Setpoint (0-55%VWC) 18.96 | Pulse Type: Micropulse 240 | Edit

Select which moisture sensor ports to use for control (selected sensors must be the same type and will be averaged together):

☒ Port 1 ☐ Port 2 ☐ Port 3 ☒ Port 4 ☐ Port 5

Click on start and end point to create (or delete) schedule below View All Schedules

9am 10am 11am 12pm 1pm 2pm 3pm 4pm

submit

Send Manual Irrigation Command

- Sensor-based irrigation control scheduled for 15 minutes every hour
- Within each 15 minute period, able to irrigate up to three, 4-minute pulses (i.e. 240s on, 60s off)
- *Only irrigates* if the minimum soil VWC is reached (currently set at 19% VWC)

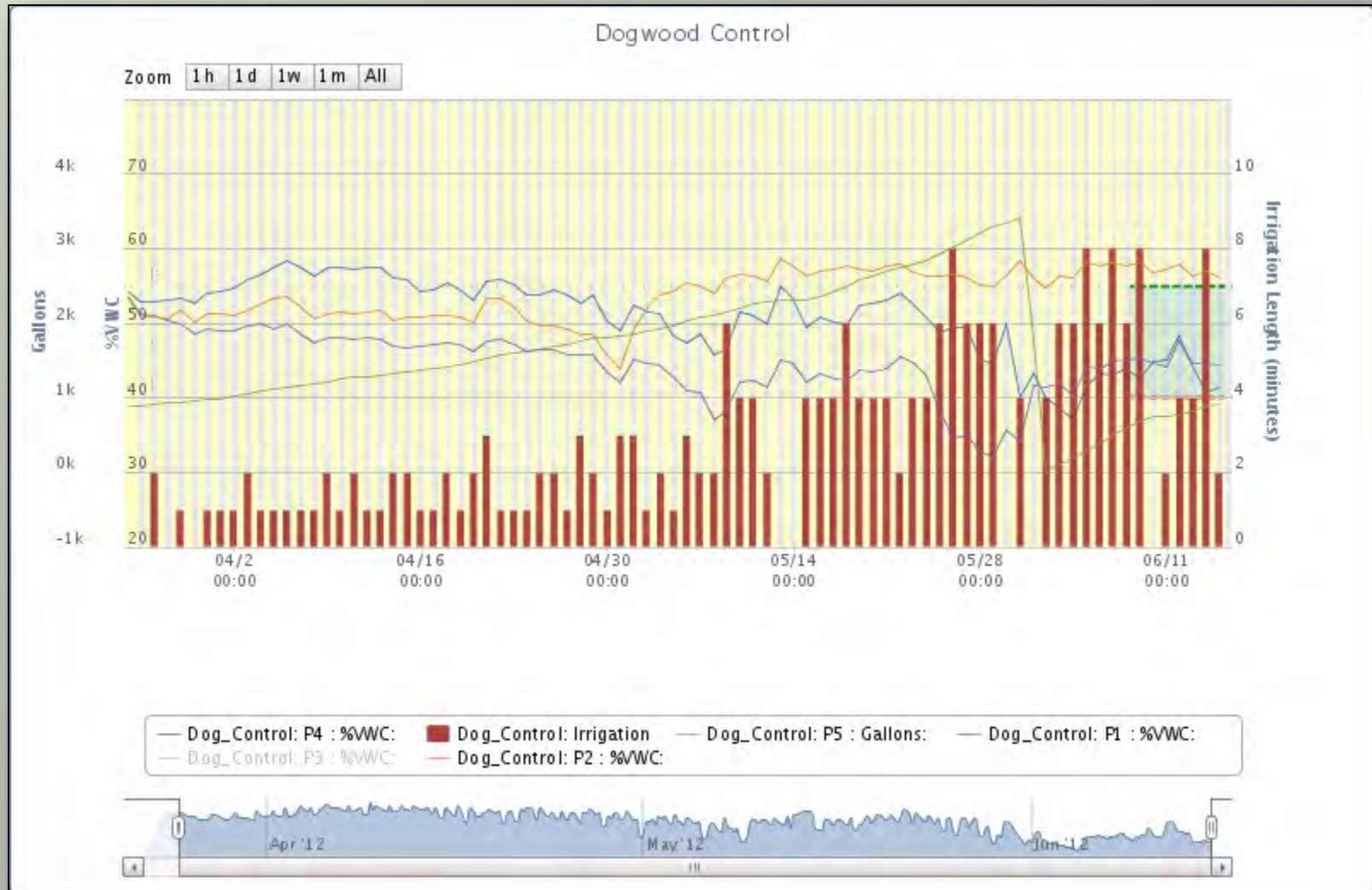
Software Capability: Micro-Precision Irrigation

- **Turning Data into Information**
- **Measuring Variability:**
 - Averaging Capability (any sensor, any node)
- **Acting on that Information:** – Automated Micro-pulse Irrigation



Enables remote and/or automatic control of irrigation schedules, via a customizable web-based interface

Sensor-Controlled Irrigation Scheduling



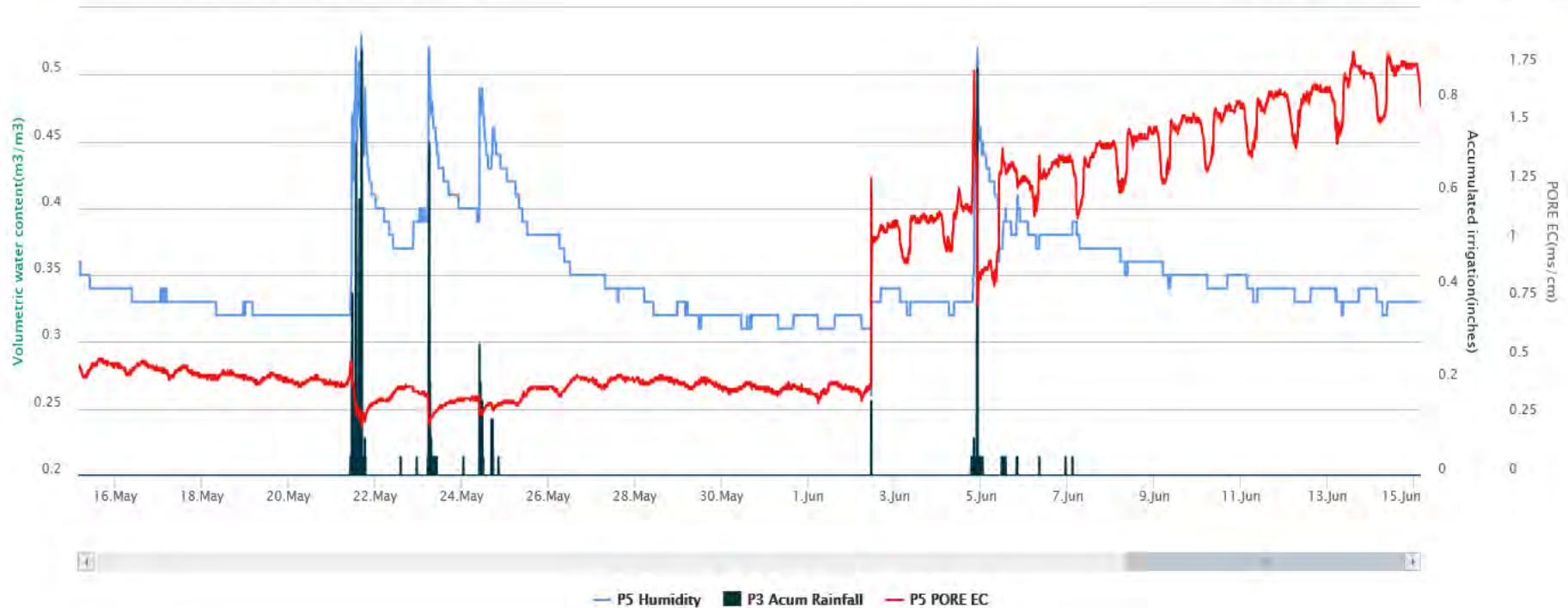
Real-time EC Monitoring: Integrating Data




IRRIGATION GRAPH %VOL

Zoom 12h 24h 3d 7d 15d **1m** 3m All

From 05/15/2017 To 06/15/2017



SensorWeb Alert Capability



Mayim Sensorweb

- Dashboard
- Data View
- Charts
- Irrigation
- Alerts
- Data Export

OptiRiego Sensorweb

Feb 22 2016 22:55 CET • 8:10 Sunrise 19:12 Sunset

Sensorweb Alerts

Triggered Alerts Add Alert

Active	Alert Name	Alert Frequency	Source	Set Point	Notification Address
<input checked="" type="checkbox"/>	Exp Control VWC Alert!!!	Evaluated every 60 minutes	Exp_Control - P1: Soil Moisture (10HS) (Mineral Soil)	Alert sent when below 17.0	jlc@umd.edu, belayneh@umd.edu, sebastien@optiriego.com, miguelangel@optiriego.com
<input checked="" type="checkbox"/>	Exp R4 MPS-6 Sensor Alert	Evaluated every 60 minutes	EXP R4 - P5: MPS-2C/MPS-6 Water Potential/Temp	Alert sent when below -15.0	jlc@umd.edu, belayneh@umd.edu, sebastien@optiriego.com, miguelangel@optiriego.com
<input checked="" type="checkbox"/>	Exp R4 VWC Alert	Evaluated every 60 minutes	EXP R4 - P1: Soil Moisture (10HS) (Mineral Soil)	Alert sent when below 18.0	jlc@umd.edu, belayneh@umd.edu, sebastien@optiriego.com, miguelangel@optiriego.com
<input type="checkbox"/>	Experimental Control Setpoint	Evaluated every 30 minutes	Exp_Control - P1: Soil Moisture (10HS) (Mineral Soil)		

Update Alerts Active

Alert Settings

Alert Active: ☐ Name: _____

How often should alerts be checked: ?

☒ Fixed interval (every x minutes)

☐ At a specific time (ex. 16:30)

Please enter the time or frequency to monitor alerts (based on options above): ? _____

Set item for alerts to monitor: _____

Set alert setpoint value to _____, and send alert if value goes above the setpoint value.

Notification type: ? E-Mail Notification to: _____

Create Alert

* You are responsible for any text message or other charges resulting from alerts generated by this system. This system makes no guarantee about the alert being sent out properly.

- Alerts can be set for any node or sensor, at a specified time or set-point threshold value
- Alerts can be texted or emailed to any user

The Process

Data ➡ Information ➡ Knowledge ➡ Action

The System

Sensors ➡ Software ➡ 'Analyst' ➡ Decision-Maker



Irrigation Efficiency – Return on Investment

Table 4. Water price comparisons and returns from changing timed cyclic irrigation into sensor-controlled irrigation.

Costs and benefits	Water price [per 1000 gal (3.785 m ³)] ^z			
	\$0.17	\$1.00	\$2.00	\$3.00
Benefits	2.7 year ROI		4-month ROI	
Pumping cost savings	\$ 8,137	\$46,944	\$94,189	\$141,283
Management cost savings	\$12,150	\$12,150	\$12,150	\$12,150
Annual savings	\$ 20,288	\$59,094	\$106,339	\$153,433
Costs				
Annualized sensor system cost	\$14,205	\$14,205	\$14,025	\$14,025
Annual maintenance	\$ 1,000	\$1,000	\$1,000	\$ 1,000
Total sensor system cost	\$15,205	\$15,205	\$15,025	\$15,025
Annual net savings	\$ 5,263	\$44,069	\$91,313	\$138,408

^zCorresponding water prices = \$55, \$326, \$652, and \$978 per acre-foot; \$1/acre foot = \$8.1071/hectare-meter.

Fungal Disease Management



Gardenia 'radicans' - high shrinkage due to crop death/unmarketable final product.

Reduction in Production Times, Net Benefits

- ✓ 14-month production cycle collapsed to 8-month
- ✓ 30% loss to Disease reduced to virtually zero
- ✓ Economic Gain = \$1.06 / ft²
(total net revenue = \$20,700 for crop)
- ✓ ROI < 3 months for \$6,000 network



Lichtenberg, Chappell et al., 2013 HortTechnology 23:770-776

Increase in Crop Quantity and Quality



35,000 square foot greenhouse production

- Produces 475,000 stems of Cut Snapdragons, Sunflowers per annum
- Hydroponic culture using recirculating water and nutrients
- Perlite substrate in bags, monitored with EC-5, GS3-EC sensors; Tank with EC, pH
- Canopy environment monitored with air Temp / RH (VPD) and light (PAR) sensors

Economic Analysis: Annual Profitability

Pre-Sensor: (2007 – 2009)

Post-Sensor: (2010 – 2012)

	2007 -2009	2010- 2012	Difference	Change
Crops/ year	37	38	1	1 %
Stems/ year	106,308	139,382	33,074	31 %
Price/ stem	\$ 0.59	\$ 0.62	\$ 0.03	5 %
Labor costs	\$ 15,905	\$ 17,893	\$ 1,988	12 %
Electricity	\$ 4,109	\$2,923	\$ 1,186	-29 %
Sensor system	\$ 0	\$7,147	\$ 7,147	---
Revenue	\$63,094	\$ 85,679	22,585	36 %
Profit	\$43,080	\$57,716	\$14,636	34 %

Payback period on upfront costs: <16 months

On-farm Weather Station

DS-2 Sonic Anemometer
Wind speed and direction

VP-4
Temp, RH, VPD,
Barometric Pressure

Pyranometer
Solar Radiation

QSO-S PAR
PAR (visible light)

ECRN-100 Rain gauge
Precipitation

**Em50G “cloud –based”
data logger**



Environmental Data Applications

Soil Temperature

- planting timing (seed/transplants)
- seed emergence
- nematode activity

Temperature

- foliar spray timing (leaf scorch/phytotoxicity)
- spray records
- plant stress/spray performance (esp. herbicides)

Relative Humidity

- general labor scheduling
- foliar spray timing
- spray records (performance)
- pruning timing (disease risk - i.e. Eutypa)

Leaf Wetness

- foliar spray timing
- spray records (performance)

Precipitation

- general labor scheduling
- spray timing
- spray records (performance)
- spray wash-off

Wind

- general labor scheduling
- spray timing
- spray records (drift injury/performance)
- plant injury/stress
- irrigation

Dashboard – Single Node Data



Welcome
SCRI Weather



MAP



DASHBOARD



CHECKBOARD



FORECAST

SCRI-WATER3 > CATOCTIN MOUNTAIN GROWERS > 5G117171_CATOCTIN WEATHER



DEGREE DAYS 2017

Zoom: 1d 3d 7d 15d 1m 3m All



RAINFALL

0

1 Day

0

7 Days

2

30 Days



TEMPERATURE / RELATIVE HUMIDITY

89 °F

Last data

48.00 %

Last data



TEMPERATURE MIN / MAX

MAX

95 °F

95 °F

95 °F

MIN

66 °F

46 °F

44 °F

Language

English

Español

Français

Date

dd/mm/YYYY

mm/dd/YYYY

Home

Map

Dashboard

Checkboard

Alarms

Flow

gal

ml

2

m3

l

Electrical Conductivity

ms/cm

dS/m

MS/cm

Volumetric Water Content

%

cm/m

lpf

m3/m3

Counts

0

Wind direction

°

Relative humidity

%

Time

min

h

Rainfall

l/m2

mm

Inches

Water Potential

Kpa

Bar

Atmospherical pressure

kPa

bar

Vapour pressure

kPa

bar

Pressure switch

psi

kpa

Radiation

W/m2

Photosynthetically active radiation

umol/m2 s

Temperature

°C

°F

Wind speed

km/h

mph

m/s

Depth

cm

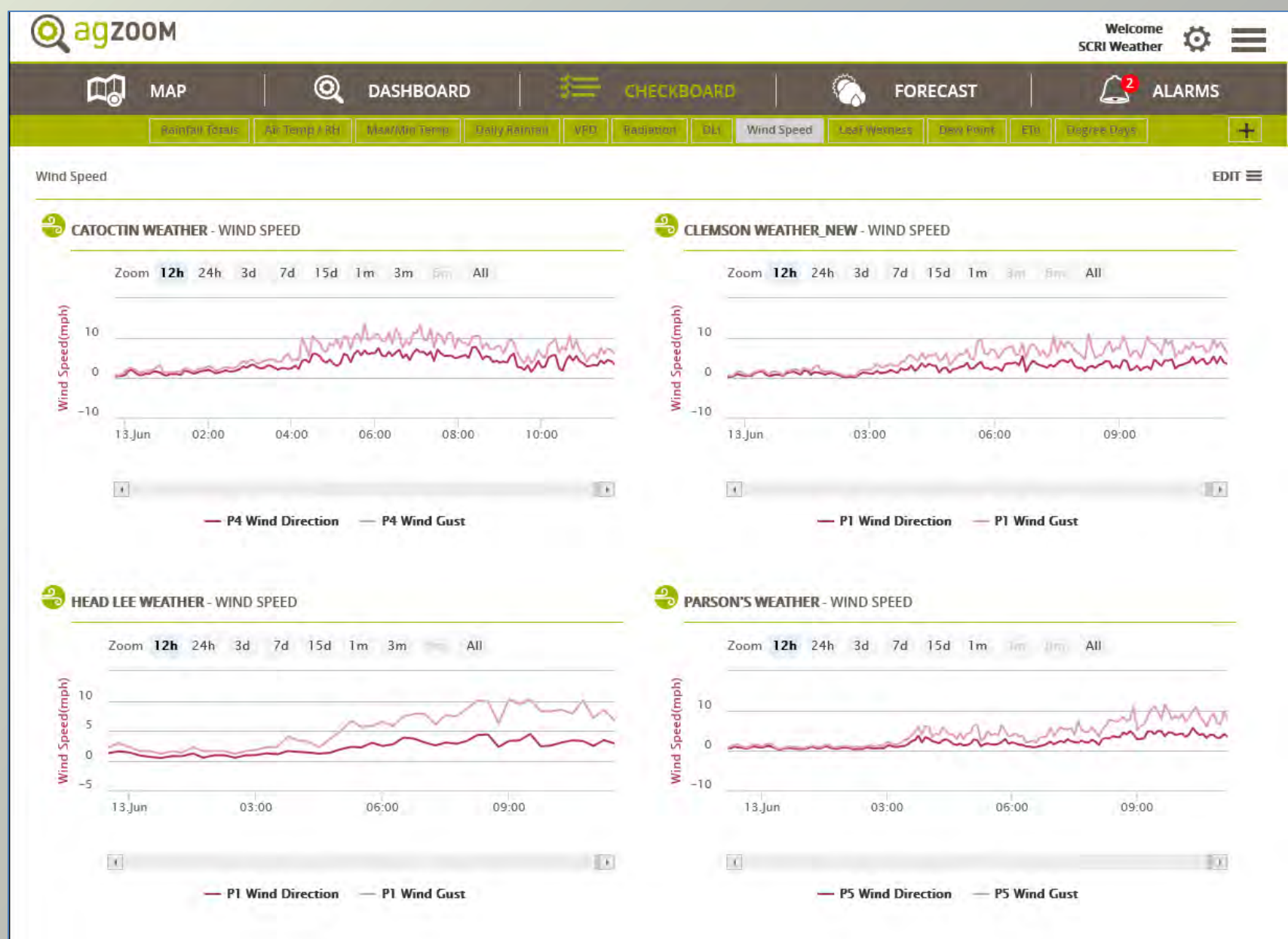
Inches

Depth


cm

Inches



Checkbox – Aggregate Data





Geolocated 7-Day Weather Forecast





Welcome
SCRI Weather




MAP

DASHBOARD

CHECKBOARD

FORECAST

2ALARMS

Forecast:

Weather Bush 'n Vine Farm

47.56°N 7.59°E 247m asl

Forecast

7-day weather

14-day weather

Current weather

Webcams

Meteograms

Multimodel

Detail

Weather maps

Weather maps (New)

Special

Archive / Climate








history+

Products

Widget


News

Feedback

















	Wed Tomorrow	Thu 6-15	Fri 6-16	Sat 6-17	Sun 6-18	Mon 6-19	Tue 6-20
							
	81 °F	87 °F	74 °F	74 °F	83 °F	84 °F	
	60 °F	63 °F	61 °F	55 °F	57 °F	60 °F	63 °F
	↔ 5 mph	↔ 9 mph	↔ 10 mph	↓ 6 mph	↔ 7 mph	↔ 8 mph	↔ 7 mph
	☀ 4h	☀ 9h	☀ 8h	☀ 13h	☀ 12h	☀ 10h	


Find the weather for the next hours on the [current weather](#) page.

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 Smartphone apps: Try our brand new [meteoblu app for android](#) or our updated [iPhone and iPad app](#).

Wednesday

	02 ⁰⁰	05 ⁰⁰	08 ⁰⁰	11 ⁰⁰	14 ⁰⁰	17 ⁰⁰	20 ⁰⁰	23 ⁰⁰
								
Temperature (°F)	63°	60°	62°	72°	79°	80°	78°	69°
Temperature felt (°F)	63°	60°	61°	73°	81°	81°	79°	71°
Wind direction	↗ SSW	↙ SW	↑ S	↖ NE	↓ N	↘ SE	↗ E	↖ E
Wind speed (mph)	2-6	2-7	4	4-8	5-9	5-7	4-6	4-5
Precipitation (in/3h)	-	-	-	-	-	-	-	-
Precipitation probability	0%	0%	0%	10%	0%	20%	10%	10%
Precipitation hourly								
rainSPOT								
Precipitation distribution within 15 km								

UV 9

↑ 05:35
↓ 21:23



↑ 00:06
↓ 10:02

Water temperature Rhein: 20°C
Pressure: 1015 hpa
Timezone: CEST
Domain: NEMS4
Last model run: 2017-06-13 21:31

☐ Show details / hourly data

Impacts

Synergistic Capabilities:

1. Precision Water and Nutrient Management
2. Timeliness of Decisions; Opportunity Costs
3. Intelligent Alerts
4. Better Predictive Capabilities

Can translate into Multiple Benefits:

1. Reduced Risk and Crop Losses
2. Reduction in Production Times
3. Increased Crop Yield and Quality

Project Information at <http://smart-farms.net>

Smart Farms Home | Smart Farms - Mozilla Firefox

File Edit View History Bookmarks Tools Help

smart-farms.net

Google

Smart Farms Home | Smart Farms

Smart Farms Knowledge Center

Smart Farms


SCRI-MINDS—Managing Irrigation and Nutrition via Distributed Sensing

saving water increasing efficiency reducing environmental impacts

HOME APPROACH ENVIRONMENTS R&D TEAMS RESEARCH SITES PARTNERS ECONOMICS PUBLICATIONS IMPACTS

Smart Farms Home

- Network Development
- Direct Sensing Approach
- Modeling Approach
- Advisory Panel



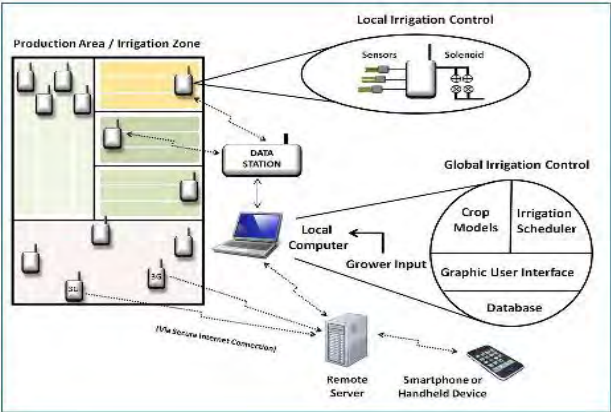
Smart Farms Home

Our project is all about saving water, increasing efficiency and reducing the environmental impacts of ornamental plant production practices! We are using wireless sensor networks and environmental modeling to more accurately predict and apply irrigation water in nursery and greenhouse operations, and monitor green roofs for stormwater mitigation.

Our goal is to provide growers with the ability to precisely monitor and control applications of water and nutrients to plants in these production settings, based upon daily plant requirements.

Our vision is to provide the nursery and greenhouse industries with cost-effective equipment and strategies that can be used to reduce the volume and cost of inputs, increase profitability, reduce the environmental impacts of nursery and greenhouse production and encourage sustainable practices in the United States and beyond.

The purpose of this website is to provide you with an overview of our project and information about the research and development of an advanced environmental monitoring and irrigation system. We are actively collaborating with a number of commercial growers using their production areas as test environments. These collaborations will help us learn to best implement this new technology to minimize cost and maximize efficiency.



```
graph TD
    subgraph "Production Area / Irrigation Zone"
        direction TB
        P1[Plant 1]
        P2[Plant 2]
        P3[Plant 3]
        P4[Plant 4]
        P5[Plant 5]
        P6[Plant 6]
        P7[Plant 7]
        P8[Plant 8]
        P9[Plant 9]
        P10[Plant 10]
    end

    subgraph "Local Irrigation Control"
        direction TB
        S[Sensors]
        Sol[Solenoid]
    end

    subgraph "Global Irrigation Control"
        direction TB
        CM[Crop Models]
        IS[Irrigation Scheduler]
        GUI[Graphic User Interface]
        DB[(Database)]
    end


    P1 --> DS[DATA STATION]
    P2 --> DS
    P3 --> DS
    P4 --> DS
    P5 --> DS
    P6 --> DS
    P7 --> DS
    P8 --> DS
    P9 --> DS
    P10 --> DS

    DS --> LC[Local Computer]
    LC --> GIC[Global Irrigation Control]
    GIC --> LC
    GIC --> RS[Remote Server]
    RS --> GIC
    RS --> SHD[Smartphone or Handheld Device]
    SHD --> RS
```

SCRI - CLEAN WATER³

REDUCE, REMEDIATE, RECYCLE

[search](#) [ask an expert](#) [feedback](#)



home conserve water control pH & salts remove contaminants monitor quality training tools research about

[Research outputs](#) [Research overview](#) [Project impact](#)

Topics:


- MOST RECENT
- ANNUAL REPORT (1)
- CARBON & WATER FOOTPRINT (6)
- CONSERVE WATER (14)
- CONTAINER SUBSTRATE (6)
- CONTROL PH & SALTS (2)
- ECONOMIC COST (6)
- MONITOR QUALITY (8)
- NUTRIENTS & AGRICHEMICALS (9)
- PARTICLES & DEBRIS (2)
- PATHOGENS & BIOFILM (5)
- TOOLS & MODELS (2)

Most Recent

6 FEB 2017

Elimination of Tobacco Mosaic Virus From Irrigation Runoff Using Slow Sand Filtration

Oki, L.R., Lee, E., Pitton, B., Nackley, L., (University of California (UC) Davis), Bodaghi, S., Mathews, D.M. (UC Riverside), Haver, D. (UC South Coast Research and Extension Center)



Slow sand filters have been shown to remove pythiaceous organisms from captured runoff water. In this study, Tobacco Mosaic Virus (TMV) was regularly added to irrigation runoff water. The virus passed through the sand filters for approximately 5 weeks, but gradually reduced to undetectable virus titer using ELISA during week 6 to 9. This is the first report that showed slow sand filters removed TMV from runoff water.

See the article in the link below

<http://dx.doi.org/10.1016/j.scienta.2017.01.036>

14 DEC 2016

When Exactly Should I Irrigate?

Lea-Cox, J. (University of Maryland)

"Increase crop growth and quality with proper irrigation management." Learn about basic substrate properties, and how to use moisture sensors as an irrigation management tool.

Click on the link to view the article

<http://www.gpnmag.com/article/when-exactly-should-i-irrigate/>

<http://www.watereducationalliance.org>

U.S. Department of Agriculture SCRI Award 2014-51181-22372.