CONTINUING PROJECT REPORT **YEAR**: 2 (2011)
WTFRC Project Number: TR-09-909

Project Title: Dense distributed environmental sensing via wireless sensor networks

PI: George Kantor
Organization: Sensible Machines, Inc.
Telephone: 412-867-8665
Email: george.a.kantor@gmail.com
Address: 100 Boundary St.
City: Pittsburgh
State/Zip: PA 15207

Cooperators: Jim McFerson (WTFRC), Jay Brunner (WSU-Wenatchee), Lauren Bissey (Decagon Devices)

Total Project Request: **Year 1:** $25,000 **Year 2:** $10,000

Other funding sources :

Agency Name: USDA Specialty Crops Research Initiative
Amt. awarded: $5.4M (plus $5.5M non-federal match)
Notes: As faculty at the Carnegie Mellon University Robotics Institute, Dr. Kantor is a Co-Project Director on the project titled *Precision Irrigation and Nutrient Management for Nursery, Greenhouse and Green Roof Systems: Wireless Sensor Networks for Feedback and Feedforward Control (PINM)*. This project will further develop and apply the CMU sensor network for distributed sensing and irrigation control in horticultural environments (greenhouse, nursery, and green roof). This project has been funded for five years, beginning October 2009.

Agency Name: USDA Specialty Crops Research Initiative
Amt. awarded: $6.1M (plus $6.1M non-federal match)
Notes: Dr. Kantor is also Co-Project Director on the project titled *Comprehensive Automation for Specialty Crops (CASC)*. CASC has a broad charter to investigate and develop automation technologies for specialty crops, with a specific focus on the apple industry. Much of the CASC work is being done in Washington orchards providing Dr. Kantor with resources that can be leveraged to partially support the anticipated travel requirements of this proposal to WTFRC. CASC is a fully funded four-year project that began in October 2008.

WTFRC Collaborative expenses:

Item	9/1/2009-9/1/2010	9/1/2010-9/1/2011
Stemilt RCA room rental		
Crew labor	$3,120	$3,120
Miscellaneous		
Total	$3,120	$3,120

Footnotes:

Budget 1

Organization Name: Sensible Machines, Inc. **Contract Administrator:** Stephan Roth
Telephone: 412-398-2694 **Email address:** sroth@sensiblemachines.com

Item	9/1/2009-9/1/2010	9/1/2010-9/1/2011
Salaries	$5,000	$2,000
Benefits		
Wages		
Benefits		
Equipment		$5,500
Supplies	$500	
Travel	$3,500	$2,500
Miscellaneous		
Total	$25,000	$10,000

Footnotes:

Original Objectives

The overall objective of this project is to prove the viability of distributed wireless sensing for use in orchards and to begin building relationships with WSU personnel to find new ways to use the resulting data. The specific objectives stated in the original proposal (July 2009) were:

1. Establish a 12-node sensor network to sense temperature in a Washington orchard. The network will cover an area of approximately 20-40 acres (fall 2009).
2. Demonstrate real-time frost/freeze monitoring during the spring seasons of 2010 and 2011.
3. Demonstrate reliable, continuous operation over two-year period (fall 2009 – fall 2011).
4. Work with WSU and WTFRC scientists to integrate data stream with scientific modeling efforts that make use of temperature data.
5. Build relationships with other scientists (Zhang, Whiting, WSU Prosser; Jones, Brunner WSU Wenatchee; Lewis, Hoheisel, WSU Extensions) and private sector technology providers and identify new applications for sensor networks in orchards.
6. Use data from this installation to develop proposals for additional funding through the USDA Specialty Crops Research Initiative and other agencies.

In the second year of the project, these objectives were expanded to include:

1. Build a dedicated shed and install a stable power supply for the sensor network basestation at Sunrise orchard.
2. Expand the sensing capabilities of the Sunrise network to include soil moisture, light, and wind speed/direction measurements.
3. Reconfigure the existing network to better suit the needs of ongoing scientific research at Sunrise.
4. Establish a small test network at a commercial site and use it to inform water management.

Significant Findings

A 10-node sensor network was installed at the WSU Sunrise Orchard in December of 2009 and it was operated continuously though the 2010 and 2011 growing seasons. The sensor network is a commercially available system provided by Decagon Devices with a modified user interface developed by Carnegie Mellon University to provide real-time remote access to the data. It has performed well over the course of the past 2 years, withstanding extreme heat (~105F) and cold (~0F). There was a major reconfiguration of the network in February 2011 to expand the sensing capabilities in support of ongoing research efforts by WSU researchers (Vince Jones, David Granatstein). It has required almost no maintenance except for changing the batteries. The nodes take 5 AA Alkaline batteries, which have lasted an average of 6 months at a data rate of one set of measurements every 5 minutes. Real-time cellular access to the data has been reliable. As of this writing (November 2011) the network has been taken down for the season, though we plan to bring it back up to support various activities during the 2012 growing season.

A 2-node sensor network was installed at the Auvil Vantage orchard during the last week of February 2011. This system employs Decagon Devices’ new cellular node technology, which allows the nodes to communicate and upload data directly to a remote data server without the need for an on-site base station. These nodes were equipped with soil moisture sensors installed at three different depths. There are two different types of soil moisture sensor of each node: matric potential sensors (MTS-1), and volumetric water content sensors that also measure temperature (5TM). These nodes have been in continuous operation since their installation.

Results and Discussion

This section contains detailed descriptions of the two sensor network installations (Sunrise and Auvil Vantage) and some discussion of future work.

WSU Sunrise Sensor Network

2010 Network Configuration and Data Access

Figure 1 shows the node locations for the 2010 Sunrise network as red dots. In 2010, every node was identically configured with Decagon Temperature/Relative Humidity sensors positioned at approximately 2 feet, 6 feet, and 10 feet above the ground (see Figure 2). The data from the 2010 season (April 10 – September 20) is available via the web at http://sensorweb.frc.ri.cmu.edu:40080/cgi-bin/data.cgi (username: guest, password: guest). The data is retrievable in date-stamped data files in multiple formats. The most straightforward to use is the CSV format, which can be imported directly into Excel. Figure 3 shows how to parse the data in the CSV files. Figure 4 shows data from a typical week.

2011 Network Configuration and Data Access

Figure 1 shows the node locations for the 2011 Sunrise network as green dots. In 2011, the nodes were all configured differently, and new sensing was added to measure wind speed/direction, soil moisture, and solar radiation. The exact configurations of the various nodes are described in Table 1. This data is available via a more sophisticated web interface that allows for charting of the data directly in a web browser (Figure 5) and also allows for a custom export of the data in a variety of formats. The data is available at http://sensorweb.frc.ri.cmu.edu:3404/ (username: guest, password: guest).

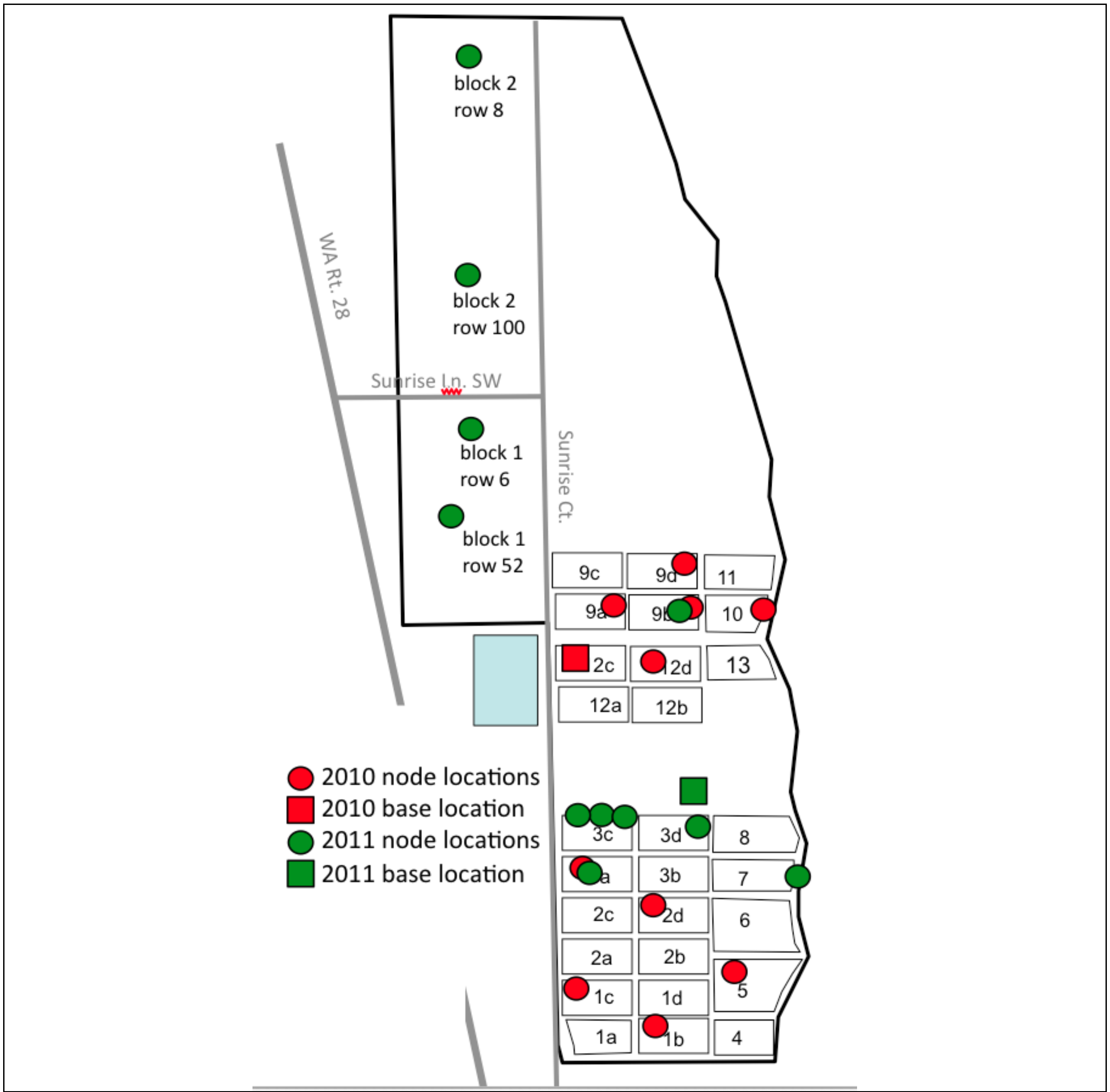

Figure 1: Node placement for Sunrise sensor network during 2010 and 2011 seasons.

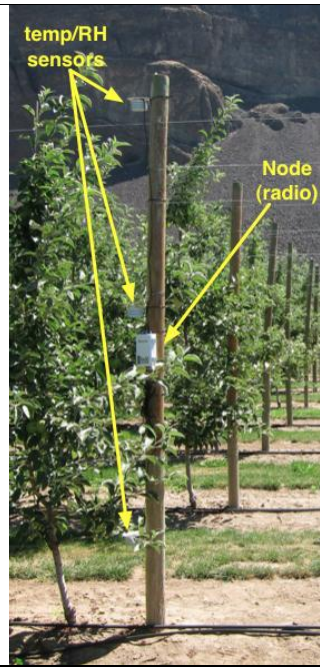

Figure 2: Sensing configuration for 2010 season (Temp/RH sensors at 2 feet, 6 feet, and 10 feet above the ground)

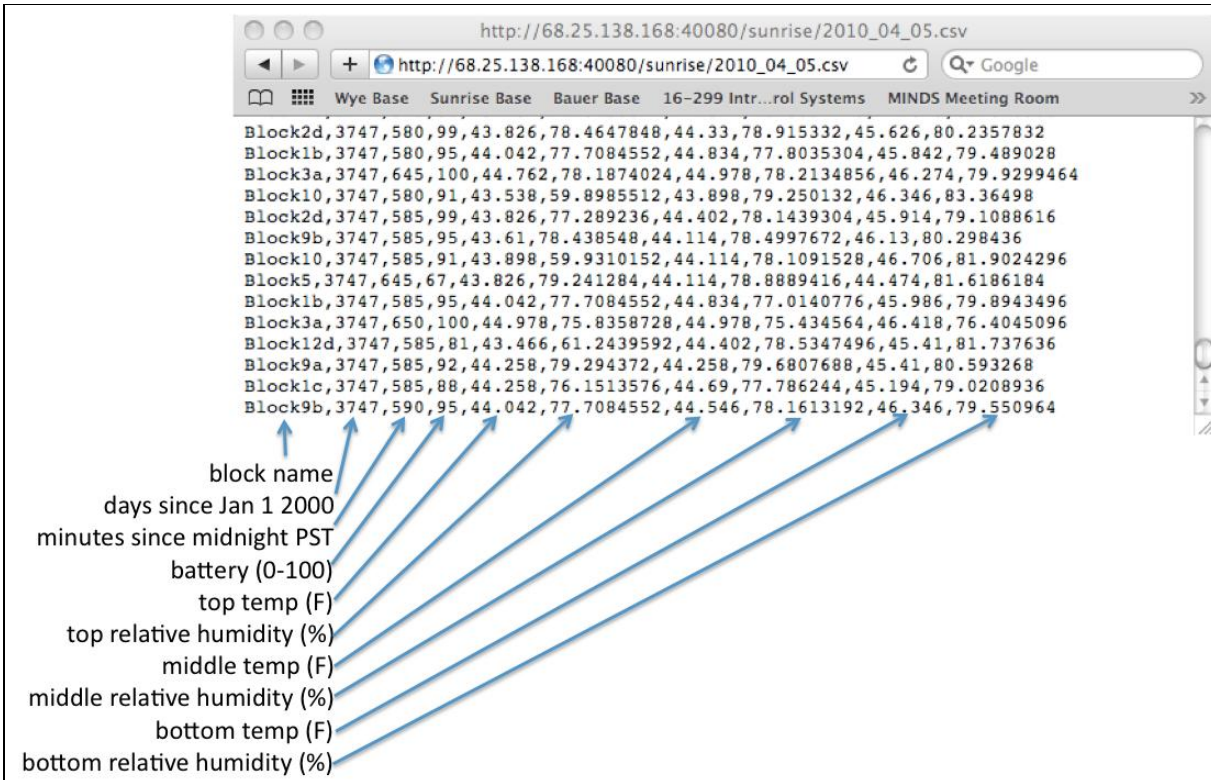

Figure 3: Instructions for parsing the CSV file format for the 2010 Sunrise sensor network data.

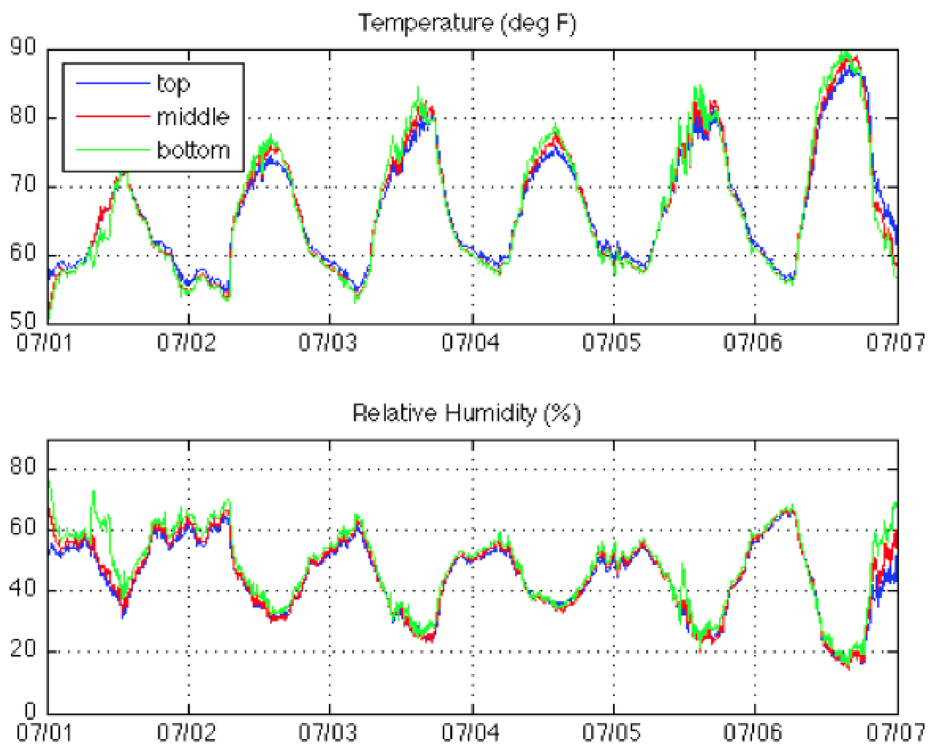

Figure 4: Temperature and RH data from a typical week at Sunrise during the summer of 2010.

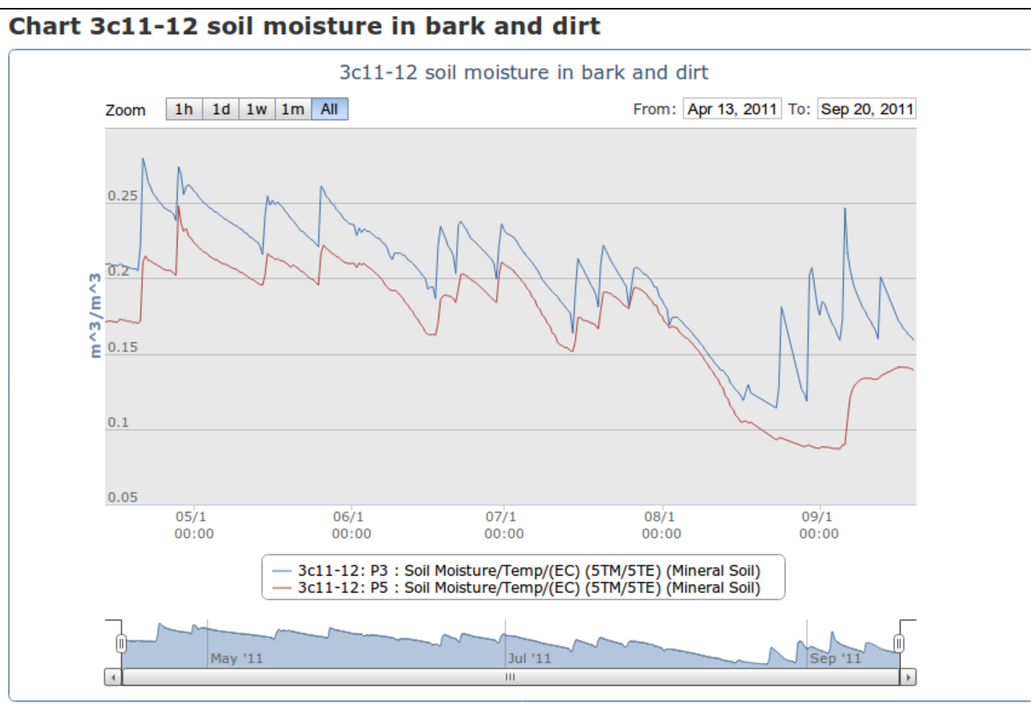

Figure 5: Soil moisture data collected at the Sunrise site during 2011, displayed using the newly developed user interface with built-in charting tool.

Node Name	Location	Sensor Configuration
Blk1_52	Organic block 1, row 52	P1 - 14" temp/RH P2 - 5' temp/rh P3 - moisture 8" depth
Blk1_6	Organic block 1, row 6	P1 - 14" temp/rh P2 - 5' temp/rh P3 - moisture 8" depth
Blk2_8	Organic block 2, row 8	P1 - anemometer above canopy (~15') P2 - anemometer in canopy (~7.5') P3 - rh below caopy P4 - rh in caopy P5 - rh above caopy
Blk2_100	Organic block 2, row 100	P1 - anemometer above canopy (~15') P2 - anemometer in canopy (~7.5')
3c11-12	Block 3c, plots 11 and 12	P1 - temp/rh in canopy P2 - matrix in bark 20cm P3 - moisture in bark 20cm P4 – no sensor P5 - moisture in dirt 20cm
3c9-10	Block 3c, plots 9 and 10	P1- temp/rh in canopy P2 - matrix at 20cm in dirt P3 - moisture at 20cm in dirt P4- matrix at 10cm in dirt P5- moisture at 20cm in dirt
3c21-22	Block 3c, plots 21 and 22	P1 - qso above caopy (mult 5.0) sp-110 (pyr) P2 - moisture 10cm in dirt hole 1 P3 - moisture 20cm in dirt hole 1 P4 - moisture 10cm in dirt hole 2 P5 - moisture 20cm in dirt hole 2
Block3a	Block 3a, Eastern edge	P1 – anemometer above canopy P2 – temp/rh in canopy
Block7	Block 7, Western edge	P1 – anemometer above canopy P2 – temp/rh in canopy
Block3d	Block 3d	No sensing

Table 1: Sensing Configurations for 2011 Sunrise Network

Auvil Vantage Sensor Network

A 2-node sensor network was installed at the Auvil Vantage orchard during the last week of February 2011. This system employs Decagon Devices' new cellular node technology, which allows the nodes to communicate and upload data directly to a remote data server without the need for an on-site base station. These nodes were equipped with soil moisture sensors installed at three different depths. There are two different types of soil moisture sensor of each node: matric potential sensors (MTS-1), and volumetric water content sensors that also measure temperature (5TM). The node locations were chosen to be near some of Auvil's existing Neutron Probe moisture sensors so that data from the new

Decagon system can be directly compared to Auvil's current standard practice. Node locations and a view of some typical data are shown in Figure 6 and Figure 7.

The data from this new setup can be viewed remotely using the following instructions:

1. go to http://www.decagon.com/products/data-loggers-and-collectors-2/data-management-software/datatrac-3/ to download and install Decagon's DataTrac3 software.
2. Open DataTrac3 and go to Settings > Create New > Em50G
3. Enter the user ID 5G0B0253 and password udko-bleur. This will give access to soil moisture data from the node placed in block 52, a Granny Smith block in the Northwest corner of Auvil. Sensors are connected to the various ports as follows:
    - Port 1: content/temperature at 12"
    - Port 2: content/temperature at 24"
    - Port 3: matric potential at 6"
    - Port 4: matric potential at 18"
    - Port 5: matric potential at 30"
4. Repeat step 2., this time enter user ID 5G0B0254 and password glit-shots. This will give access to soil moisture data from the node placed in block 30, a Fuji block on the eastern edge of Auvil. Sensors are connected to the various ports as follows:
    - Port 1: content/temperature at 12"
    - Port 2: content/temperature at 24"
    - Port 3: matric potential at 6"
    - Port 4: matric potential at 12"
    - Port 5: matric potential at 18"

Figure 6: Positioning of nodes at Auvil Fruit Vantage pilot network.

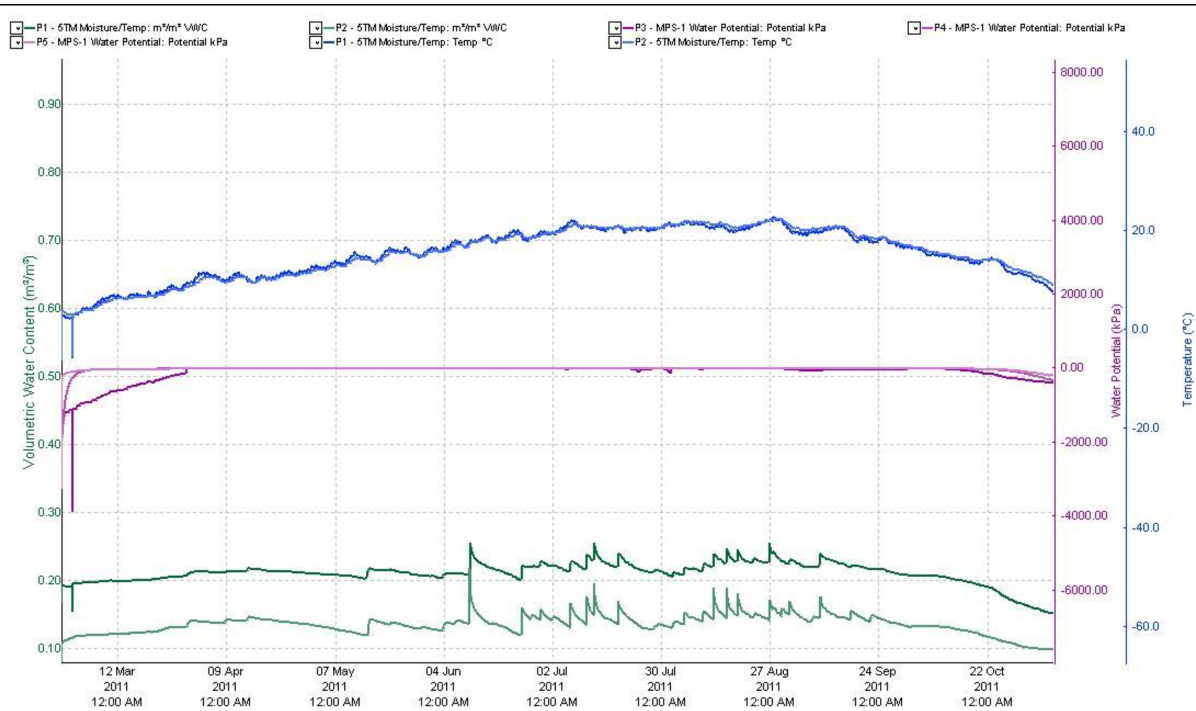

Figure 7: A plot of typical soil moisture profile measured by the Auvil Vantage pilot network.

Executive Summary

The basic objectives of this project were to establish that sensor networks are a tool that can be reliably used in for science and management in apple orchards. Over two years, we established two networks using commercially available equipment and used them to collect data continuously over the growing season. We can say conclusively that sensor networks work well in orchards and that basic environmental parameters (temperature, soil moisture, wind speed/direction, soil moisture, etc.) can be reliably measured and transmitted to a remote observer in real time. What is less clear is how to best use the massive data streams that result. We have begun to form relationships with scientists at WSU and with commercial growers to determine scientific and practical uses for sensor network data, however there is still much work to be done in this area. The equipment that was purchased for this project will remain in the field, and we will leverage funding from non-WTFRC continue to support it and explore its use with our partners. The PI welcomes future contact from potential new users of the data.

Some specific technical details of the two networks are:

A 10-node sensor network was installed at the WSU Sunrise Orchard in December of 2009 and it was operated continuously though the 2010 and 2011 growing seasons. The sensor network is a commercially available system provided by Decagon Devices with a modified user interface developed by Carnegie Mellon University to provide real-time remote access to the data. It has performed well over the course of the past 2 years, withstanding extreme heat (~105F) and cold (~0F). There was a major reconfiguration of the network in February 2011 to expand the sensing capabilities in support of ongoing research efforts by WSU researchers. It has required almost no maintenance except for changing the batteries. The nodes take 5 AA Alkaline batteries, which have lasted an average of 6 months at a data rate of one set of measurements every 5 minutes. Real-time cellular access to the data has been reliable. As of this writing (November 2011) the network has been taken down for the season, though we plan to bring it back up to support various activities during the 2012 growing season.

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