Using Wireless Sensor Technology to Schedule Irrigations and Minimize Water Use in Nursery and Greenhouse Production Systems©

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We have deployed and are evaluating two types of wireless sensor networks to provide real-time data for precision irrigation management, and to reduce nutrient leaching from the root zone in three ornamental production environments. A commercially available sensor network (Decagon Devices, Inc.) is being used to monitor the effects of rainfall, irrigation water applications, soluble nutrient applications, soil and air temperature, and photosynthetically active radiation data on the growth of two indicator species in a field (soil) production environment. Another type of research wireless sensor network [Carnegie Mellon University (CMU)] has been deployed at two different sites; one network is deployed in a production greenhouse environment, the other is deployed in a container-nursery research study. This last network is being used to automatically monitor and control irrigation water applications and the leaching of nutrients from soilless substrates in the container-production of four ornamental species. In this paper, we will give an overview of our progress to date and the additional research and development needed to provide real-time data for irrigation scheduling decisions by nursery and greenhouse growers.

INTRODUCTION — OUR GOALS

We are all concerned about water in one way or another — concerns over drought and water availability from groundwater or surface reservoirs; water quality; nutrient and chemical runoff; capture and recycling issues; and various local, state, and federal regulations all are focusing us in one way or another on the water that will be available for intensive ornamental plant production in the future. Almost all growers have issues with water management, but oftentimes the most basic issue is the estimation of daily plant irrigation requirements. While this question seems trivial, plant water requirements vary by species, season, and microclimate, and depend upon any number of environmental and plant developmental factors that need to be integrated over time; thus precision irrigation scheduling in nurseries is extremely difficult, given the number of species and the length of crop cycles ranging from a few months to several years. There are many approaches to this issue, and the status of soil and plant water status can be measured in many different ways. Jones (2008) provides a comprehensive mini-review of the advantages and disadvantages of various technological methods to assess plant water requirements.

Plants integrate daily environmental factors such as light, temperature, water, and nutrient availability, with growth as the summation of these factors. For many of the reasons outlined by Jones (2008), we have chosen to focus our efforts on the direct measurement of water in the root zone, since daily plant requirements are reflected in the amount of plant-available moisture in the root zone. Furthermore, we need to sense other environmental information in real time (e.g., soil and air temperature, canopy relative humidity, leaf wetness, wind speed, and photosynthetically active radiation), so we can integrate and provide this information as a suite of prediction tools that can be used for either manual or automated decisions. This suite of data will also allow us to model and better predict plant growth and provide additional information for insect and disease prediction models and to make better business management decisions in the future.

Our basic premise is that if we can accurately sense the real-time water use of plants by monitoring soil or substrate moisture, and relate that accurately to plant water use, we will be able to more precisely schedule irrigation and nutrient applications. Of course this requires that we overcome some real challenges in the next few years, which we will discuss in more detail later in this paper. However, we have already shown that this approach can substantially reduce water use, leaching of nutrients, and overall runoff from container-nursery production environments (Ristvey et al., 2007). Van Lersel et al. (2005), Nemali and van Iersel (2007), and Bowden et al. (2005) have shown similar results with soil-sensing technology, and have made good progress towards linking the measurement of soil moisture with plant water use and physiological responses to changing water content. It is vital that any moisture sensing technology work equally well in soilless substrates (e.g., peat, perlite, pine bark, and other non-soil substrates) as in soils. Since many of these substrates are very porous (to facilitate drainage from containers), many of the soil moisture sensing technologies outlined by Jones (2008) have been shown to perform poorly in container production. This is the primary reason that we have focused on low-cost capacitance sensors, which we have shown have good precision in a range of soilless substrates (Arguedas et al., 2007a, b).

This paper provides an overview of our deployment of networks of sensors in nursery and greenhouse production environments to measure plant-available moisture in real time and work towards automating irrigation events for individual blocks or species of plants. Since these sensor nodes are portable and connect wirelessly to the network, growers can rapidly deploy them in any area of the operation, to maximize the utility and cost of the sensors. Also, since these networks are scaleable, additional nodes can be added, allowing for an operation to grow and/or improve their sensor network at any time.

CURRENT SENSOR NETWORK CAPABILITIES

The current capabilities of the two sensor networks that we are testing are illustrated in Table 1. Both networks currently have good basic capabilities, but our goal is to produce a hybridized "next generation" sensor node that incorporates the best features of each system in the near future. Briefly, the major benefits of the Carnegie Mellon University (CMU) system is that it has a mesh network capability (i.e., the nodes automatically communicate with each other) which is important for large-scale (>10 ha) operations or in hilly terrain (Fig. 1). The CMU nodes also have a local control capability (which can average data from a number of moisture sensors), which can then used to actuate a solenoid for automated irrigation scheduling in blocks independent of a main (central) computer system. The fact that the CMU node can accept up to 10 sensor inputs is also important to maximize data transmission cost and the functionality of any individual node in the field. The Decagon Devices Inc. (Pullman, WA) EM50R node (Fig. 2) is extremely robust and well-engineered, has a more powerful radio card (necessary for connecting over large distances to the "base" radio station) than the CMU system, and has excellent power conservation capabilities (more than 6 months on 5 "AA" batteries), when data are collected every 15 min from the attached sensors. The Decagon Devices EchoTrac software also has a good basic graphic user interface; however both network systems lack a truly robust data management system necessary for advanced irrigation control functionality.

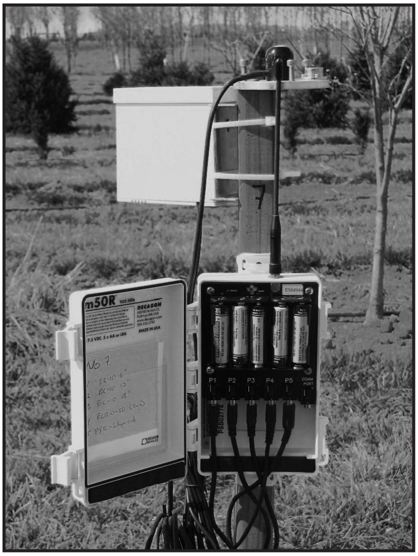

Figure 1. Decagon Devices EM50R node.


Figure 2. Carnegie Mellon University node.

Table 1. Summary of Carnegie Mellon and Decagon devices network features.

Components	Decagon wireless monitoring system	CMU wireless sensor network	Comments
Nodes	See Fig. 1	See Fig. 2	Two wireless sensor networks currently being tested and compared.
Networking	Point-to-multipoint	Mesh and point-to-multipoint	The simplicity and robustness of point-to-multipoint is appealing, but mesh networking is required for operations where line of sight to base is not feasible.
Radio	High power 900MHz, 2 mile line of sight range	Low power 900MHz, 100 m line of sight range	High power radios are more robust to interference and signal attenuation due to foliage.
Sensor interface	5 analog / digital = 5 sensor inputs	5 analog + 5 digital = 10 sensor inputs	Systems are comparable, though more inputs provide more flexibility.
Battery Power	5 “AA” batteries with 6+ month life	4 “D” batteries with 3–6 month life, dependent upon data logging and actuation demand	Battery life needs further optimization with increased data logging and transmission requirements.
Control	None	Set point solenoid control, currently used for irrigation (single set point for all nodes)	Control is required for automated irrigation, set points should be individually programmable.
Local Data storage	1 MB (33,000 data points)	None; data storage in local mother node	Local data storage is necessary for continued safe operation during communication failures.
Interface	DataTrac graphic user interface allows selection, manipulation, and time-series plotting but is not web based	Web-based text files (non-graphical)	Web-based graphical interface is required for ease of use; adds flexibility and convenience

SENSOR NETWORK DESCRIPTIONS

Readers may refer to <http://www.sensornet.umd.edu> for a more detailed description of our test deployment sites.

Tree Farm (Adamstown, MD). A 12-node commercial wireless sensor network (Decagon Devices Inc.; Pullman, Washington), is currently installed in two blocks at this ornamental field-grown tree farm. The sensor network is monitoring soil water status at three depths within the root zone of six *Acer rubrum* 'Franksred', Red Sunset® red maple and six *Cornus florida* 'Cherokee Princess' trees in real time (Lea-Cox et al., 2008). In addition, soil temperature, soil electrical conductivity (EC), rainfall, irrigation water applications, air temperature, relative humidity, and photosynthetically active radiation (PAR) are continuously measured. We are also measuring tree growth on a monthly basis with trunk diameter data. The primary objectives are to evaluate the performance of these sensors in soils and the capability of the network to provide real-time data for day-to-day decisions regarding precise management of water and soluble nutrient applications.

Wye Research and Education Center (Queenstown, Maryland). A 12-node CMU network, hybridized with Decagon Ech20 moisture sensors is being used to monitor and automatically control irrigation applications in real time in a container-nursery research site. This is achieved by precisely monitoring the substrate matric potential, based on substrate-specific calibrations (Arguedas et al., 2007). We are also quantifying water applications and nutrient leaching in a comparative research study, comparing sensor-controlled irrigation events to cyclic irrigations controlled by time clock (current best management practice; Tyler et al., 1996). The primary objectives are to quantify the reduction in water use and nutrient leaching at the micro-scale (Ristvey et al., 2007).

Cut-flower Greenhouse (Jarrettsville, Maryland). A 6-node CMU network — hybridized with Decagon Ech20 moisture and electrical conductivity (Ech20-TE), air temperature, relative humidity, and PAR sensors — is being used to monitor a 1-acre cut-flower greenhouse production facility. This greenhouse is a closed-system hydroponic (perlite) system that grows *Antirrhinum* (snapdragon) taxa year round. All water and nutrients are continuously recycled. The primary production objectives are to automatically schedule water (based upon matric potential) and nutrient solution (based on substrate EC) applications up to 20 times per day, ultimately to increase the percentage of #1 cut flower stems during the summer months. This will require the same network capabilities as we are currently testing, but in a more demanding environment with rapid temporal changes.

PROGRESS TO DATE

The Decagon Devices network has performed very well at the tree farm during 2008, with data gathered from a range of sensors in the field, including the EC-5 and 10HS soil moisture sensors. The sensors and nodes have had very few issues either in deployment or operation. Custom soil calibrations did provide more precise data than the factory set calibrations, as would be expected (Lea-Cox, Black et al., 2008). The graphic user interface (GUI) software which graphs the data from each individual node is simple and easy to use, and provides the grower with information that has only been available from very expensive cumbersome research sensor systems, until now. We monitored current irrigation practices and environmental conditions in the two blocks of indicator species during 2008, to establish baseline management data. The intent is to only irrigate half of the trees in each block when necessary during 2009, to quantify any water use and plant growth differences.

We are using the CMU network at the Wye research site to automatically monitor and control irrigation events based on custom calibration data for the pine bark substrate, based in the matric potential (plant-available water content) of the substrate (Arguedas et al., 2007a). Irrigation set points are at a matric potential of approximately -10 kPa (ON) and -2 kPa (OFF) to minimize leaching events. Since the spray stakes [Netafim Yellow; 200-300 mL output per minute at 1.72 bar [25 PSI)] are used in relatively small (8 L) containers to provide adequate coverage, a micro-pulse routine was written into the sensor node software, to irrigate in 1-sec pulses. Using this technique, enough time (a few seconds) elapses between micro-pulses for the sensors to then measure the new substrate matric potential, before additional micro-pulses are applied. In this way, leaching volumes can be precisely controlled to minimize nutrient leaching. We are currently quantifying water applications and nutrient runoff with current best management practices (cyclic time irrigation events) compared to sensor-controlled irrigation method in a replicated experiment using four plant species (Ristvey et al., 2007).

To date, we have shown that the measurement of soil or substrate moisture can provide precise information to schedule irrigation events in both soil and soilless substrates. Both sensor networks perform well in the field, although some networking challenges remain with remote sites (line of site transmissions greater than 1 mile), as could be expected in large operations. A higher power radio card in the CMU nodes is being tested to overcome this limitation, which would increase the cost of this node. However, the cost per node for the CMU network would still be considerably below the current cost of the Decagon EM50R. In our estimation the cost structure of the sensors is less of a factor compared to the cost of the nodes. The solenoid actuation capability of the CMU node is a vital control function which many nursery growers agree is necessary for maximum utility and labor savings.

ADDITIONAL RESEARCH AND DEVELOPMENT

There are many areas where we need additional research and development, to provide the maximum cost benefit of these networks for growers. We need a more robust database management system that would provide the backbone to the graphic user interface, able to handle networks of more than 10 nodes (50–100 sensors). This database should be able to manage rapid computations and statistical analysis, for example, similar to GPS and business systems that are used to track packages in real time. These systems also need to be web-enabled, so that employees can access sensor data with hand-held devices in the field, using the same wireless networks that transmit the data to the office computer (server). Growers also need to have a manual control (override) capability, most likely as the default setting. However, greenhouse growers need an automated capability, due to the shorter time period between irrigation events in these production systems.

Most importantly, we need to connect our capability for precision water applications with knowledge of real-time plant water use. We need to improve our ability to predict plant water use in real-time using various technologies. We think that modeling plant water use for indicator species, similar to the results published by Bauerle and his group in recent years (e.g., Wang et al., 2007; Bowden et al., 2005;

Bauerle et al., 2002; 2004; 2006), as an integral part if the prediction capability of the software has the most promise in the near term. In conclusion, we are making some rapid progress in our ability to accurately monitor and control irrigation scheduling in nursery and greenhouse environments. With continued support from the industry, we hope to provide this capability and our cumulative knowledge to all plant producers in the near future.

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