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Use wireless sensor networks for improved, cost-effective irrigation management in nurseries and greenhouses.

Wireless *Water* *Management*

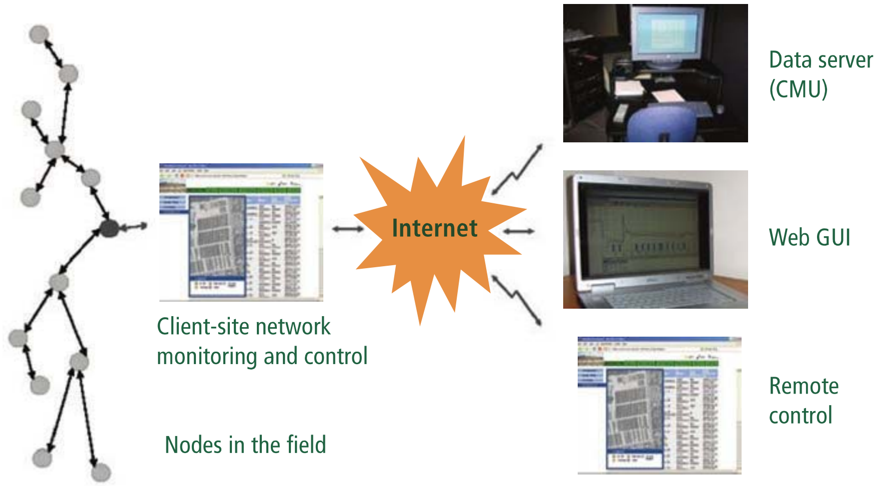
Recent events with energy, labor and the economy have been foremost in the news of late, but one of those perennial issues — water, the lifeblood of our industry — is still an issue for many producers. Recent droughts affecting surface-water and groundwater availability, water quality, nutrient and chemical runoff, capture and recycling issues, and various local, state and federal regulations all are focusing us — in one way or another — on the quantity and quality of water that will be available for ornamental plant production in the future.

Almost all growers have some issues with water management, but oftentimes the most basic question is, "Should I irrigate today?" While this question could seem 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 on a day-to-day basis. Add to these factors the number of species grown in a "typical" operation and the length of crop cycles, which can range from a few months to several years, and it quickly becomes obvious why precise irrigation scheduling in nurseries is extremely difficult. If done well, daily irrigation decisions take a lot of time, and the irrigation manager often faces complex decisions about scheduling that requires the integration of knowledge at many levels. Irrigation management is, therefore, probably one of the most complicated tasks in a nursery operation, particularly when water is limited.

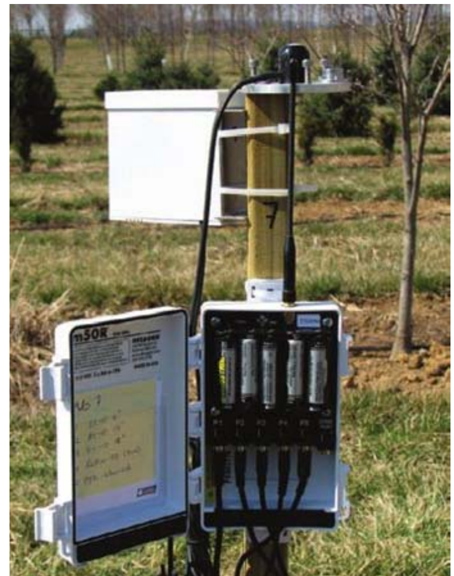
Technology options. Over the years, there have been many technological advances touted to aid in the irrigation-management decision process. Various soil-moisture measurement devices — tensiometers, gypsum blocks, meters that directly sense soil moisture and weather station/satellite forecast data that integrate environmental information with evapotranspiration models — are all available, and yet widespread adoption of any technology has not occurred for good reasons.

First, many sensing technologies, which were originally engineered for soil-based measurements, have been applied to soilless substrates. They have largely failed because these sensors did not perform well in highly porous substrates, which is the physical property that is necessary for good root growth in containers. Even when a technology was adapted successfully to container culture — for example, low-tension tensiometers — it often has been too expensive for wide-scale adoption or there have been precision or maintenance issues. Cost and ease of use are key aspects to adoption and use of any tool.

by John D. Lea-Cox, Andrew G. Ristvey *and* George F. Kantor



This schematic of a wireless sensor network shows how the system provides real-time data for precise irrigation and plant growth management.



A Decagon Devices Inc. EM50R node is connected to a tipping rain gauge, light (photosynthetically active radiation) sensor and three soil-moisture sensors (not visible) in the field.

Decagon Devices Inc. node and soil-moisture sensors are being installed in a field-nursery block.

Second, macroscale weather or evapotranspiration factors are too gross a measure for precise irrigation scheduling at the microscale in nurseries. But, most importantly, the technology has often not achieved any real economic benefit for the grower in terms of water savings or improved plant growth. Very often, it merely adds another "management layer" that requires added expertise to interpret and use the information to make a decision. Therefore, we need to bear in mind these considerations when we develop any system that aims to improve upon current irrigation-management techniques.

A number of researchers have published information over the past two decades about the potential of computerized systems that have the ability to directly sense the water status of soils in the field and other large-scale situations, such as vineyards and golf courses. While these sensor systems may perform relatively well for simple on/off decisions, they are usually expensive and have other limitations for many growers, including power and communication issues in rural areas.

Higher-tech greenhouse irrigation systems have been in use for some time, but most of these systems do not provide a control ability to manage irrigation scheduling based upon daily plant water use. They mostly just monitor water applications and control water-quality information, such as pH and electrical conductivity (by adding acid and/or nutrients), or they control irrigation solenoids with a time clock — similar to advanced nursery irrigation-management systems.

New systems tested. There are new, alternative systems that show promise for both small- and large-scale nursery operations. We have deployed and are evaluating two wireless sensor networks that have the potential to provide real-time data for precise irrigation and plant growth management, and are relatively cost-effective. You may wonder what a "wireless sensor network" consists of: It is a system of radio-powered "nodes" that are deployed in an area of the nursery to which a number of environmental sensors are connected.

Any combination of soil-moisture and electrical-conductivity sensors, soil and air temperature, relative humidity, tipping rain gauge and light (photosynthetically active radiation) sensors can be connected to the nodes, according to the information that is required. These nodes then log the data from the sensors every 15 minutes to conserve battery life. When necessary (usually once or twice a day), the accumulated data is then transmitted at 900 MHz from a battery-operated radio card to a base radio station. The base station is then connected to a computer, which uses software to plot and display the information from each of the nodes. This information, in turn, can be relayed over the Internet to someone in any place, at any time.

In this way, a grower can develop a network of sensors that allows for the monitoring of environmental data in the nursery, in real time. The advantage of this network is fairly obvious: It provides information at the microscale that can be expanded to any resolution, which is determined for a specific operation and specific needs.

We believe that there are six essential priorities for any environmental sensor network:

1. The user should be able to rapidly deploy sensors in any area of the growing facility to maximize the utility and minimize the cost of the sensor network.

2. Sensors and the wireless network should be scalable, thereby allowing an operation to begin with a small system and expand/improve the sensor network over time.

3. The data from sensors should be reliably transmitted using wireless connections to the base-station computer with little or no interference over distances of 1 to 2 miles with low (battery or solar) power requirements.

4. The monitoring function of the network should automatically log data from sensors and present it in a form that provides the user with an easily interpreted view of that data, such as a spreadsheet or, preferably, in a customized graphical output.

5. The control function of the network should include minute, hourly and/or daily sensor data that is integrated by the system to automatically switch on irriga-

PHOTOS COURTESY OF GEORGE F. KANTOR; COURTESY OF JOHN D. LEA-COX

These photos show the Carnegie Mellon University network at the Wye Research and Education Center, Queenstown, MD.

PHOTOS COURTESY OF JOHN D. LEA-COX; COURTESY OF ANDREW G. RISTVEY

tion solenoids or other controller switches.

6. A small network for an initial user should cost less than $5,000 to purchase and install. Supporting documentation and easy-to-follow instructions with "plug and play" operation should allow for implementation entirely by the grower, with little or no need for support or maintenance by the manufacturer.

Our focus. Our research and development team at the University of Maryland, College Park, and at Carnegie Mellon University (CMU) Robotics Institute, Pittsburgh, is specifically focused on developing a robust capability to monitor water content and precisely schedule irrigations in large-scale nursery (both field and container) and greenhouse operations. 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 data to actual 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 will be discussed later in the article.

However, we have already shown that this approach can substantially reduce water use, leaching of nutrients and overall runoff in container nursery and greenhouse production environments. It is vital that any moisture-sensing technology works equally well in soilless substrates (peat, perlite, pine bark and other nonsoil substrates) as in soils. This is the primary reason why we focused on low-cost capacitance sensors, which we have shown have good precision in a range of soilless substrates.

Furthermore, we need to sense other environmental information in real time so we can integrate and provide this information as a suite of prediction tools that can be used for either manual or automated irrigation decisions at larger scales. You can learn more about our team, goals and objectives at www.sensornet.umd.edu.

Our sensor networks. In ongoing research, we are comparing the use and operation of two wireless sensor networks in three different production environments. One network is commercially available from Decagon Devices Inc., Pullman, WA. The other is a research network developed by the CMU Robotics Institute. Both networks currently have good basic capabilities, but the CMU system has some advanced features.

First, the CMU nodes have a "mesh networking" capability (the nodes communicate with each other, which has advantages for large-scale deployment or on hilly terrain). Second, the CMU node has a *local control* capability, meaning that the node software can average data from a number of moisture sensors, which is then used to actuate a solenoid for automated irrigation scheduling in blocks *independent* of the main computer system. Third, the CMU node can accept up to 10 sensor inputs (compared to only five with the Decagon Devices node), which maximizes the cost-effectiveness of any individual node in the field.

On the other hand, the Decagon Devices EM50R node is extremely robust and well-engineered, and has a more powerful radio card (necessary for connecting over large distances to the base radio station) compared to the current CMU system. It also has excellent power-conservation capabilities (more than nine months on five AA batteries) when data is collected every 15 minutes from the sensors.

The Decagon Devices network has performed very well on a tree farm during 2008, with data gathered from a variety of sensors in the field, including the EC-5 and 10-HS 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 was expected. The EchoTrac graphic user interface software, which graphs data from each individual node, is simple and easy to use, and has provided the grower with information previously available only from much more expensive research sensor systems.

We are using CMU nodes and Decagon Devices sensors to automatically monitor and control irrigation events in small, 2-gallon containers in a research site at the Wye Research and Education Center, Queenstown, MD. This is made possible by using custom calibration data for the pine bark substrate based on the matric potential (plant-available water content) of the substrate. Irrigation set points are at a substrate matric potential of approximately -10 kilopascals (kPa; On) and -2kPa (Off) to minimize leaching events. A micropulse routine was written into the sensor-node software to irrigate in one-second pulses. Using this technique, enough time (a few seconds) elapses between micropulses for the sensors to then measure the new matric potential before additional micropulses 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 the sensor-controlled irrigation method in a replicated experiment using four plant species.

We also deployed a hybrid CMU sensor network in a cut-flower greenhouse in 2008. This greenhouse is a closed-system, hydroponic (perlite) structure that grows *Antirrhinum* (snapdragon) species 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 electrical conductivity) applications up to 20 times per day, ultimately to increase the percentage of high-quality, cut-flower stems during the summer months. This will require the same network capabilities as we are currently testing for container nurseries, but greenhouses are a much more demanding environment with rapid, daily changes in environmental and plant conditions.

Future directions. 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, real-time, data-management system that would provide the backbone for the graphic user inter-

The Decagon Devices Inc. soil sensors are currently being calibrated and tested for use in various soils and substrates by the research and development team at the University of Maryland, College Park.

face and be able to handle networks of more than 10 nodes (50 to 100 sensors). This database also should be able to manage rapid computations and statistical analysis, for example, similar to a Global Positioning System and other business systems that are used to track packages in real time. These systems need to be Web-enabled, so employees can access sensor data with handheld devices in the field, using the same wireless networks that transmit 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 will need an automated capability because automatic irrigation control is likely a necessity in these production systems.

Most importantly, we need to connect our capability for precise water applications with knowledge of real-time plant water use. We need to improve our ability to *predict* plant water use in real time by using various technologies.

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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