Deployment of Wireless Sensor Networks for Irrigation and Nutrient Management in Nursery and Greenhouse Operations

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Significance to the Industry: 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 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 – do I need to 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. Effective daily irrigation decisions take time and the irrigation manager often faces complex decisions about scheduling that require the integration of knowledge at many levels. Irrigation management is therefore one of the most complicated tasks in a nursery operation, particularly when water is limiting. Ideally, this should be combined with real-time sensing of nutrient concentrations in the root zone, by measuring electrical conductivity (EC). Our goal is to enable the automation of this task by using wide area networks of soil moisture and EC sensors.

Nature of Work: Background: There are many technologies that over the years have been touted to aid the irrigation decision process. Various soil moisture measurement devices from tensiometers, gypsum blocks, meters that directly sense soil moisture and weather station / satellite forecast data that integrate information with evapotranspiration models are all available, and yet the widespread adoption of any technology has not occurred, for good reasons. Firstly, many sensing technologies which were originally engineered for soil-based measurements have been applied to soilless substrates. They have failed, largely because these sensors did not perform well in highly porous substrates, as aeration is a physical property that is required for good root growth in container culture. Even when a technology was adapted successfully to container culture (e.g. low-tension tensiometers), the technology has often been too expensive for wide-scale adoption or there have been issues with precision, maintenance and automation of the technology. Cost and ease of use are key aspects to adoption and use of any tool. Secondly, macro-scale weather or ET Pan factors are too gross a measure for accurate irrigation schedules at the micro-scale in nurseries, and Kc values for ornamental species are non-existent or imprecise. 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 the technology merely adds another ‘management layer’ that requires added expertise to interpret and use the data to make a decision. We therefore need to bear these considerations in mind when we develop any system that aims to “improve” upon current irrigation management techniques.

Deployed Sensor Networks: Our group has previously reported on the calibration of sensors for soilless substrates (1, 2, 3) as well as the development and deployment of specific wireless networks (5, 6, 7). In this paper, we report on the deployment and performance of two wireless sensor networks, the current challenges and benefits associated with each network and our future research directions. Briefly, we are comparing the use and operation of two sensor networks in three different production environments. One network (Fig. 1) is commercially available from Decagon Devices, Inc. (Pullman, WA); the other (Fig. 2) is a non-commercial research network developed by the Carnegie Mellon Robotics Institute (Pittsburg, PA). Each sensor network consists of a system of radio-powered “nodes” that are deployed in a plant production area, 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 radio nodes, according to the specific sensing requirements of the grower. The nodes log data on a per minute basis, and log the average data every 15 minutes, to conserve battery life and memory. The accumulated data is then transmitted at 900 MHz or 2.4 GHz using a battery operated radio card to a ‘base radio station’ whenever it is required. The base station is connected to a computer, which uses custom software to plot and display the information from each of the nodes. With the CMU network, this information is relayed over the internet (Fig. 3) to provide the information to anyone, in any place and 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 advantages of these networks are obvious – they provide information at the “micro-scale” which can be expanded to any resolution for a specific operation, for specific needs.

Both networks have good basic sensor network capabilities, but the CMU system has a few distinct advantages. Firstly, the CMU nodes have a “mesh networking” capability (i.e. the nodes communicate with each other, which has advantages for large-scale deployment or in hilly terrain). Secondly, the CMU node has a *local control* capability, which means that the software in an individual node 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 (central) computer system. Thirdly, the CMU node can accept 10 sensor inputs (compared to only five with the Decagon Devices node), which further maximize data transmission cost and the cost-effectiveness of any individual node in the field.

On the other hand, the Decagon Devices EM50R node (Fig. 1) is extremely robust and well-engineered, has a more powerful radio card (necessary for connecting over large distances to the 'base' radio station) relative to the present CMU system, and has excellent power conservation capabilities (more than 9 months on 5 'AA' batteries) when data are collected every 15 minutes from the attached 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 would be expected. The EchoTrac™ graphic user interface software (Fig. 4), which graphs the data from each individual node is simple and easy to use, and has provided the grower with information that has only been available from much more expensive research sensor systems, until now. We monitored irrigation practices and environmental conditions from two blocks of indicator trees during 2008, to establish baseline irrigation management data.

We are using a CMU sensor network in a container-production research site at the Wye Research and Education Center near Queenstown, MD (Fig. 2) to automatically monitor and control irrigation events in small (2 gallon) containers. This is possible 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 matric potential of approximately -10kPa (ON) and -2kPa (OFF) to minimize leaching events. A micro-pulse routine was written into the sensor node software, to irrigate in 1 second 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. We have also deployed the CMU sensor network in a greenhouse operation during 2008. This greenhouse is a closed-system hydroponic (perlite) system 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 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 in container culture, but in a more demanding environment with rapid temporal changes.

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 production environments, 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 slightly increase the cost of this node. However, the cost per node for the CMU network should 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.

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 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 must 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). Most importantly, we need to connect our capability for precision water applications with a 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 (4, 8) is essential to providing a prediction capability for large-scale implementation of sensor-derived data from indicator species. In conclusion, we are making some rapid progress in our ability to accurately monitor and control irrigation scheduling in nursery and greenhouse environments.

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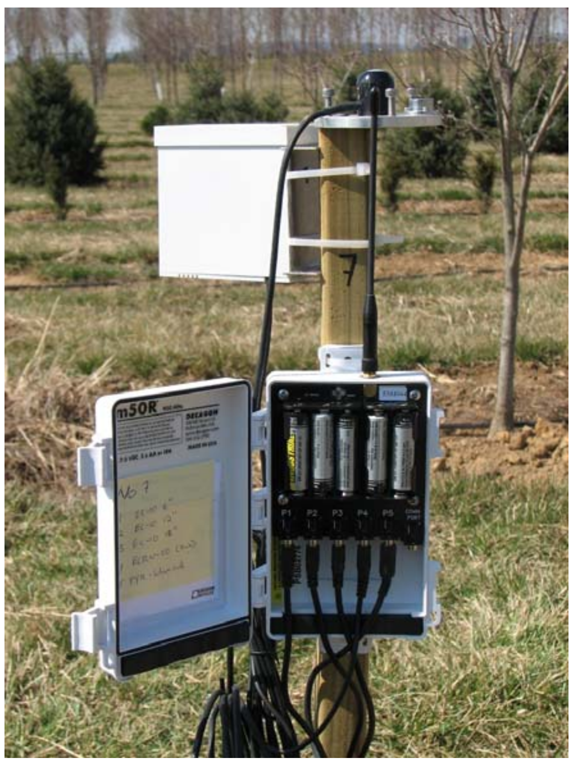

Fig. 1. A Decagon Devices EM50R node connected to a tipping rain gauge, light (PAR) sensor and three soil moisture sensors (not visible) in the field.

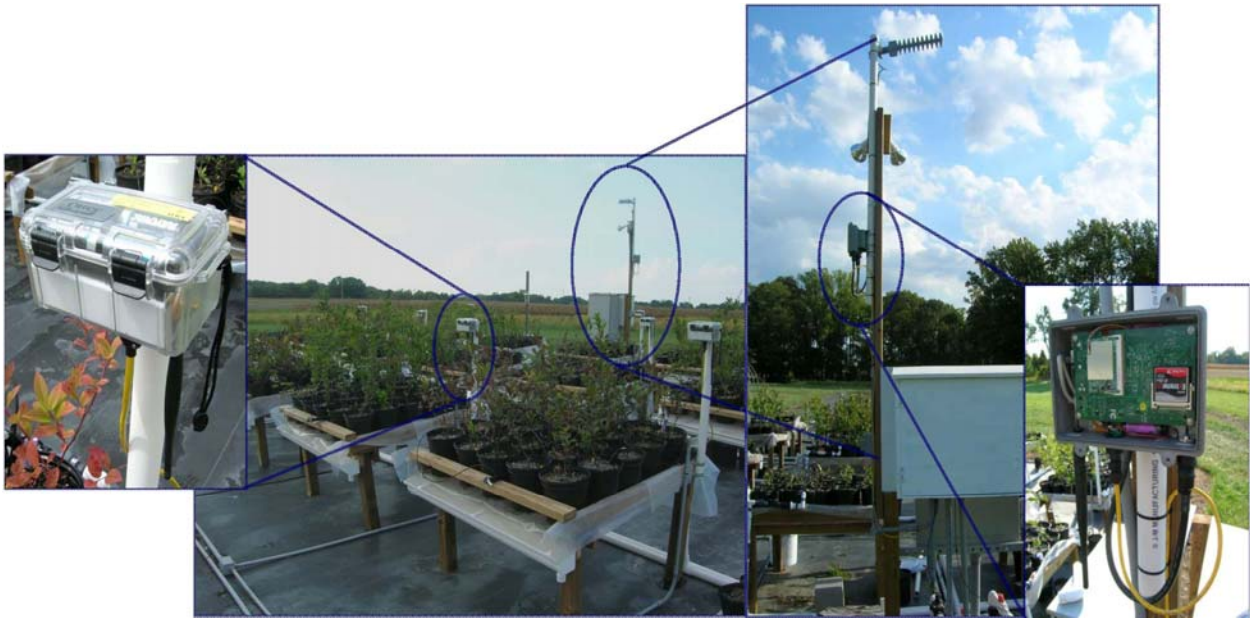

Fig. 2. The Carnegie Mellon University (CMU) network at the Wye Research and Education Center, near Queenstown, MD, showing sensor nodes (at left and centre), communication node and antenna (at right).

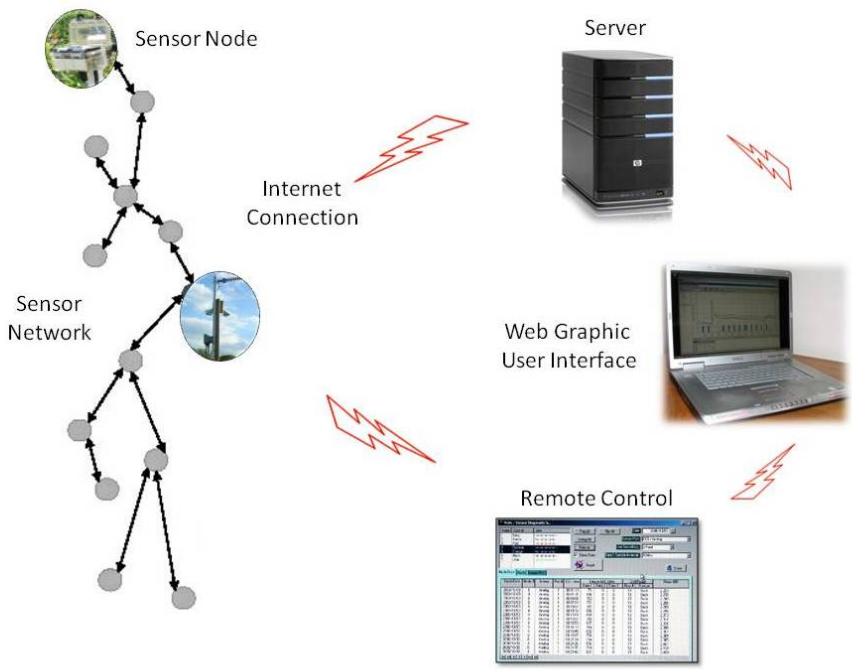

Fig. 3. A schematic of the CMU sensor network, which utilizes the internet for real-time monitoring and control of irrigation scheduling.

Fig. 4. A computer screenshot of the Decagon Devices, Inc. EchoTrac™ software, showing soil moisture data from EC-5 sensors at 6”(black), 12” (green) and 18” (purple) with rainfall and irrigation amounts from a sensor node in an *Acer rubrum* block in September, 2008.