Irrigation Complexities – Using Sensor Networks for Real-time Scheduling in Commercial Horticultural Operations

John D. Lea-Cox [1] and Bruk E. Belayneh [2]

[1] Professor; [2] Research Technician
Department of Plant Science and Landscape Architecture
University of Maryland, College Park, MD 20742-4452

Abstract: Since 2009, we have deployed current generation wireless sensor networks in tree farms, container-nurseries and greenhouse operations, working with commercial growers in five States. Irrigation scheduling in ornamental operations is complex, given the large (100 - 500) number of species grown by individual growers. Typically, estimating water use on any given day requires an irrigation manager to rationalize many sources of information, including species water use, plant size and container size (root volume), environmental conditions, and previous rainfall or irrigation applications. It is not surprising that estimates of plant water requirements are often overestimated. Irrigation applications to sensor-irrigated trees were 1.4 to 6.5 times less than applied to grower-irrigated trees during 2012, saving over 16,000 gals of water for a single row of trees, even using precision microsprinkler applications. Over the year, this saved nearly 2/3 of total water applications to this crop. With easy-to-use sensors and software, we are providing real-time information to growers who are scheduling irrigation applications more precisely, greatly reducing water use, reducing various costs and increasing profitability.

Keywords: web-based; sensor networks; decision irrigation; monitoring; control, nursery

Introduction: Automated irrigation scheduling systems are widely-used in intensive horticultural production environments, such as greenhouse, container nursery or field ornamental nurseries. Additionally, many high-value food crops are also irrigated, as are golf-course and high-value landscape settings. Currently, most growers of horticultural crops base their irrigation scheduling decisions on intuition or experience (Bacci et al., 2008; Jones, 2008; Lea-Cox, 2012), using time-based programmable devices, or by using more sophisticated irrigation-scheduling tools such evapotranspiration (E_T) models or soil-moisture sensing devices. Oftentimes, the first question that a grower or manager needs to answer is whether or not s/he needs to irrigate on that specific day. Typically, the next question is how *long* do I need to irrigate, to ensure adequate water is available for the plant? While these questions could seem trivial, plant water requirements vary by species, plant size, 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. If you then consider the number of species grown in a 'typical' nursery or greenhouse operation (oftentimes >250 species); (Majsztrik et al, 2011), the variety of container sizes (i.e. rooting volume, water-holding capacity) and the length of crop cycles, it quickly becomes obvious why irrigation scheduling in ornamental operations becomes complex, if it is to be achieved with any level of precision (Lea-Cox et al., 2001; Ross et al, 2001).

Although experiential methods for scheduling irrigations can give good results, they tend to be very subjective with different operators making very different decisions. Many times, even experienced managers make an incorrect decision, i.e., they irrigate when water is not required by the plant, or don't irrigate when it is needed. It is also surprising how many so-called "advanced" irrigation controllers which allow operators to program complex scheduling routines merely automate irrigation cycles on the basis of time, without any feedback-based sensor systems. Thus, even with advanced time-based systems, the decision to irrigate is again based solely on the operator's judgment, and the time taken to evaluate crop water use and integrate other information, e.g. weather conditions during the past few days and in the immediate future.

Many sensor technologies have been developed and used over the years to aid irrigation scheduling decisions. Various soil moisture measurement devices are available, e.g. tensiometers, gypsum blocks and meters which directly sense soil moisture (van Iersel, 2012). Additionally, pan evaporation and weather station or satellite forecast data can be incorporated into evapotranspiration (E_T) models, such as the Penman-Monteith model which is widely used in agronomic crops (Fereres et al., 2003), where crop-specific Kc values have been calculated and validated. However, the widespread adoption of most of this technology has not occurred in the nursery and greenhouse industries, for good reasons. Many sensing technologies which were originally engineered for soil-based measurements have been applied to soilless substrates. Many have failed, largely because these sensors did not perform well in highly porous substrates, since porosity is an important physical property that is necessary for good root growth in containers (Bunt, 1961). Even when a technology has been adapted successfully to container culture (e.g. low-tension tensiometers), often the technology has been too expensive for wide-scale adoption, difficult to automate, or there have been precision, reliability and/or maintenance issues. For most growers, initial cost and ease of use are key aspects to the adoption and use of any tool, since they usually don't have the time or the labor to devote to the maintenance of less robust tools.

Sensor Network Hardware and Software: Figure 1 shows the type of wireless sensor network (WSN) that we have deployed in multiple research and commercial sites during the past three years. Decagon Em50R (Decagon Devices, Inc.) wireless nodes are deployed in production blocks, and collect data from a variety of soil moisture and environmental sensors from that specific area. The accumulated data is then transmitted from each sensor node (using a 900 MHz radio card) to a 'base' datastation connected to a personal computer on the farm. The incoming data is collected and stored in a database; software (e.g. DataTrac v.3.5; Decagon Devices, Inc.) then plots and graphically displays the sensor information from each of the nodes. Nodes and production blocks can be organized within the software for ease of access. Incoming data from each node is organized and is appended to the database, and graphically displayed very easily at various time scales, depending on what question the grower/user wants to answer (e.g. what is the current soil moisture status in a particular block/species?). Data from these field nodes can also be transmitted directly to 'cloud' server, using a 3G wireless node (e.g. Em50G, Decagon Devices, Inc.). The logged data is then accessed from the server via a custom website, using the same DataTrac software previously described. In this way, a grower can install and develop a cost-effective and scalable network of sensors that allows for the monitoring of soil moisture and environmental data in real time.

The advantages of these wireless sensor networks are fairly obvious – they provide very specific microclimatic environmental information, which can be expanded to any resolution, determined for a specific production operation, for specific needs. Additional valuable information is also gained from weather station instrumentation using the same network (Lea-Cox et al., 2012),

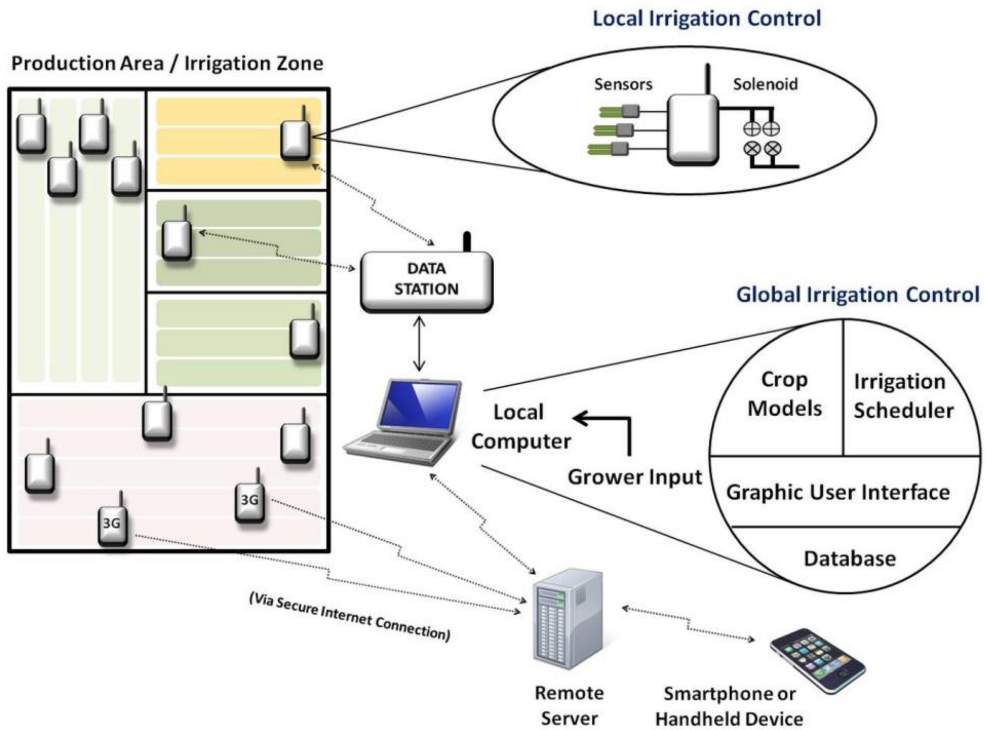

Fig. 1. Schematic of a farm-scale WSN for precision irrigation scheduling (from Lea-Cox, 2012).

including degree-days (integrated pest management), chilling hours (prediction of bud development and flowering) and other various data used for modeling purposes.

Control Node Development: Our project has also developed a battery-operated wireless node (very similar to the Em50R node, called the nR5) which is capable of both monitoring and control. It can operate normal (24V) or latching (12V) solenoids, which greatly increase the utility of these nodes for automatically controlling irrigation events in remote production blocks where there is no power (Kantor and Kohanbash, 2012). Control is achieved by using an advanced software program called Sensorweb (Kohanbash et al., 2011; Kohanbash and Kantor, 2012), which provides a custom website associated with the wireless sensor network on the farm (Fig. 2). The spatial view (homepage) is the first page that users see when they access the Sensorweb interface. This view allows users to see the state of various node locations with a quick glance. The images can be set to display different settings (and colors) by using the list at the bottom right of the page. By simply moving the mouse over an image the user can see more detailed information as well as the current trend for that measurement.

The Sensorweb software (Kohanbash and Kantor, 2012) provides growers with four operating modes: (1) a schedule-based controller very similar to what is commonly used in the industry. Within the schedule, there are two different options to over-ride the schedule to decrease the irrigation time; (2) a local setpoint controller and (3) a global controller. The schedule + local setpoint controller enables the sensor node to make local control decisions based on sensors attached to the node. The schedule + global controller allows the grower to use data from any node in the network, calculated data or model data to control the irrigation and consequently determine if the schedule should be interrupted; (4) The fourth mode is a manual override

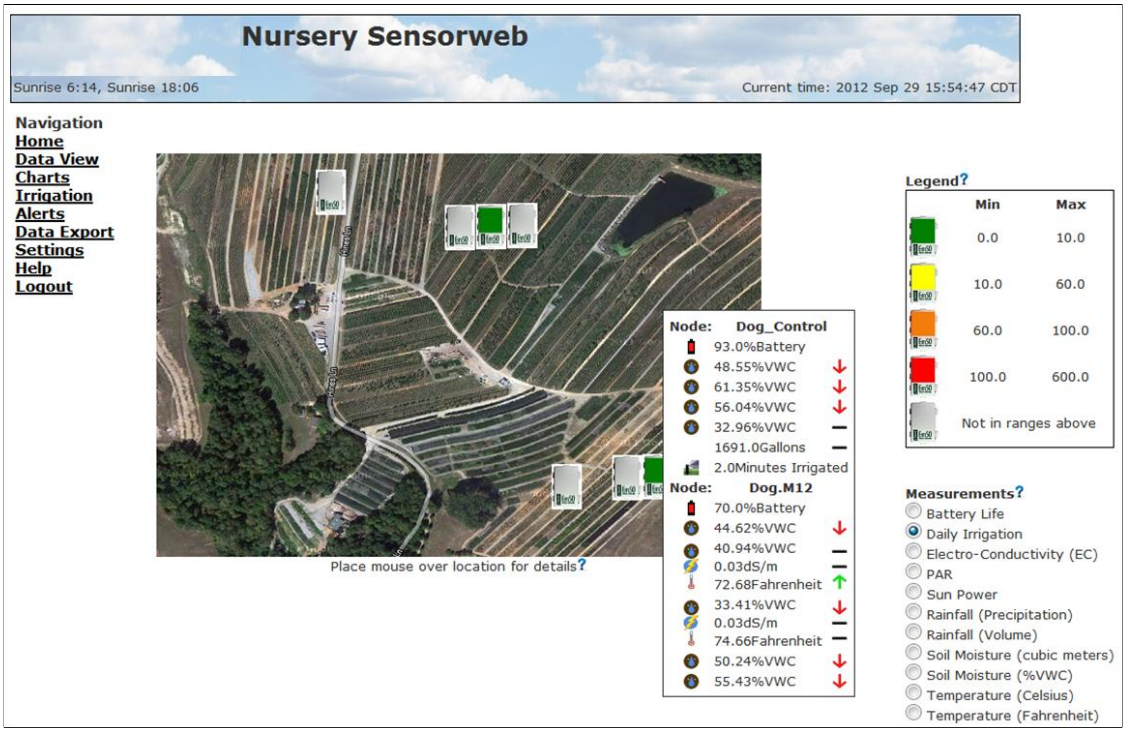

Fig. 2. The Sensorweb homepage for a wireless sensor (on-farm) network in the project.

mode that allows the grower to water in traditional mode, for a given number of minutes. This irrigation scheduling flexibility gives a grower the ability to control how water gets applied to an irrigation zone, with various user-defined parameters. The user can choose between a mode where water will be applied slowly, with small delays between irrigation events which allows water to reach the subsurface sensors (micro-pulse irrigation; Lea-Cox et al., 2009) or a mode in which water is applied continuously for a specified period of time. These modes of action are based on grower preferences and are discussed in detail by Kohanbash et al. (2012).

Sensor-Controlled Irrigation Study: To illustrate the operation and viability of this approach, we highlight some results that we have achieved using local set-point control in a large pot-in-pot container operation in Tennessee during 2012. Briefly, this large (180-acre plus) nursery produces a wide range of trees and shrubs in 10, 15, 30 and 45-gallon containers, and is a major producer of Dogwood (*Cornus florida*). Since container rooting volumes are relatively limited, and because of the pine bark soilless substrate used, irrigation scheduling needs to be much more frequent than with similar species in field soils. Leaching of nutrients from containers is also likely without careful irrigation scheduling. In a comparative study, two separate monitoring and control blocks were installed in March, 2012 – one in a block of Red Maple (*Acer rubrum*) trees, the other in a block of Dogwood (*Cornus florida*) trees (Fig.3a). There were 133 trees in both the control and the monitored rows. The control row in each block was plumbed directly from the mainline to provide independent control by the nR5 node, as shown in Fig 3b. A 12V-DC latching solenoid was installed on the control block, connected to the nR5 node, such that set-point control was enabled (Fig 4). Flow meters (Badger Meter, Milwaukee, WI) were installed on both control and monitoring rows, to provide real-time, cumulative flow data (Fig. 4). The

Fig. 3(a) The *Cornus florida* production block, showing monitoring row (daily cyclic irrigation scheduled by grower) compared to the row controlled by local setpoint control.

Fig. 3(b) The nR5 monitoring and control node, which provides local setpoint (sensor-based) control, in tandem with the 12V-DC latching solenoid (see Fig.4).

grower scheduled all cyclic irrigation events from March through Sept., 2012. An example of this is shown during June (Fig. 5).

Results and Discussion: Typically the grower scheduled 2-4 timed (6-minute) irrigation events every three to four hours during the day during summer. This irrigation frequency decreased to 1-2 irrigations per day during early spring and fall, and irrigations were interrupted for 1-2 days when rainfall occurred. In contrast, the control blocks were only irrigated when an average setpoint of <46.0% volumetric substrate moisture content was sensed by four 10HS sensors (Decagon Devices, Inc.) inserted at a 6-inch depth from the surface of the substrate in four replicate trees. Sensors were inserted horizontally in all trees at this depth, to minimize the variation due to gravitational drainage effects. A custom calibration for these sensors in this specific substrate was done prior to the study, to provide precise volumetric water content readings (data not shown). The micropulse irrigation utility of the sensorweb software was employed (Kohanbash et al., 2011; 2012), such that irrigation events in the control block were pulsed for 2 minutes, with a 3 minute interrupt period between pulse events. In this way, the relatively large amount of water applied by the microsprinkler on each tree (150 mL per minute) could be sensed more effectively by the sensors, such that when the VWC was restored above an average of 46.0%, the irrigation cycle was interrupted. This resulted in much lower leaching from each plant container (data not shown) while minimizing the irrigation cycle times. It should

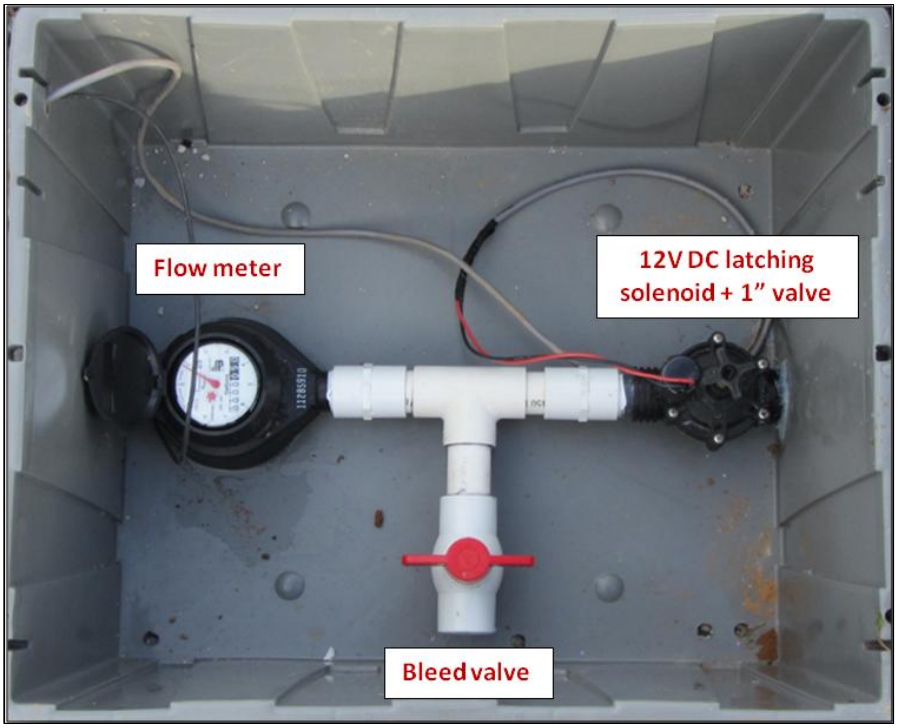

Fig. 4. The 12V-DC latching solenoid installed on the control blocks, wired to the nR5 node, which then initiated irrigations when the average substrate volumetric water content reached a setpoint of 46.0% VWC. The real-time flow meter installation is also shown.

be noted that monitoring and remote control was achieved by the team at the University of Maryland throughout the year, entirely via the website linked to the basestation and the on-farm computer in Tennessee. There were very few times that outside intervention by the grower was necessary, and in those cases, it was merely to make some minor adjustments to sensors.

Two trips were made to the operation during this period to measure the growth rate of the trees and perform minor maintenance on the various nodes in the network (including this block). As can be seen from early summer data shown in Fig.6, the control row trees were irrigated far less frequently than the trees irrigated with a normal cyclic irrigation regime (as shown in Fig. 5). This is significant, as this experienced irrigation manager was not only using his years of experience to supply the trees with adequate irrigation water, but was also following recommended best management practices for minimizing nutrient leaching, and interrupting cycles for rainfall. For the twenty-seven week period (March 24 – September 30, 2012), the average daily irrigation water applied by the grower totaled 1.035 gals / tree, compared to 0.385 gals / tree applied by the sensor-controlled irrigation (Table 1). Weekly average irrigation applications to sensor-controlled trees varied from 1.4 and 6.5 times less than weekly applications to the grower-irrigated trees. However, as of 31 August, there were no significant differences in trunk diameter or height between treatments (data not shown). The sensor controlled irrigation therefore resulted in nearly a three-fold increase in efficiency of water to irrigate these trees (Table 1), without reducing growth or quality of the trees. Similar results were shown for a similar study using a different species (*Acer rubrum*; Red Maple cv. 'Red Sunset') conducted on the same farm and during the same period (data not shown).

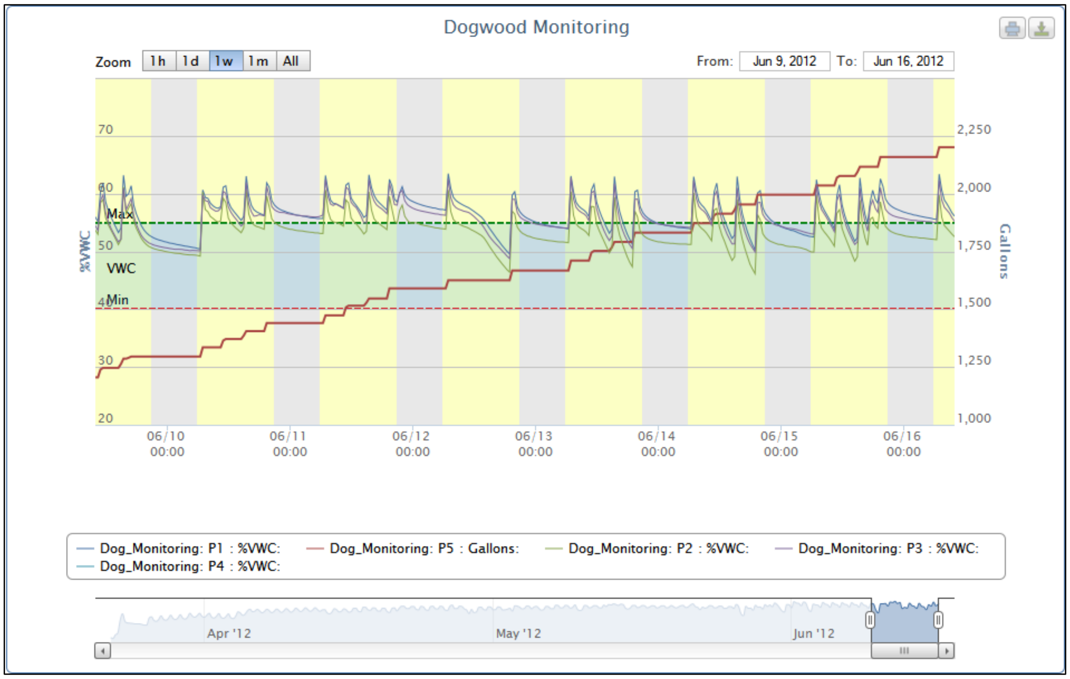

Fig. 5. A graph of substrate VWC from the10HS sensors in four individual trees (left axis) plotted by the Sensorweb software during June, 2012 for the monitored block. The red line indicates cumulative water applied per row of 133 trees (gallons; right axis)

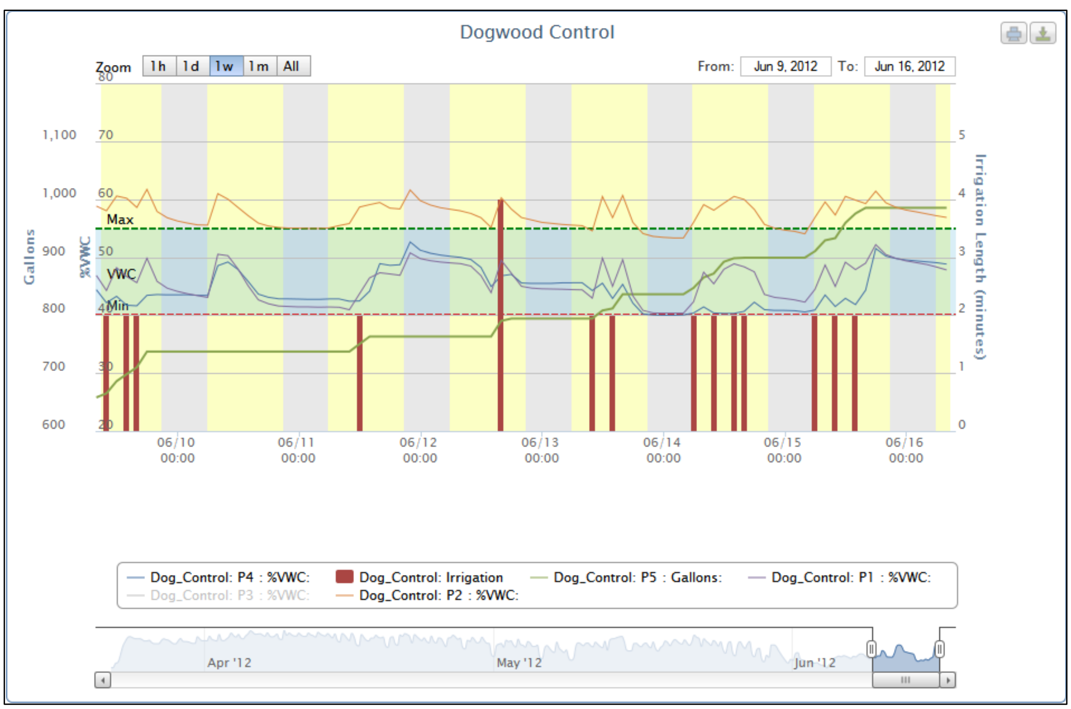

Fig. 6. A graph of substrate VWC from the10HS sensors in four individual trees (left axis) plotted by the Sensorweb software during June, 2012 for the controlled block. The red line indicates cumulative water applied per row of 133 trees (gallons; right axis)

Table 1: Cumulative water use from the monitored vs. sensor-controlled irrigated Dogwood (*Cornus florida*) trees, from 24 March through 30 September 2012.

Irrigation Method	Total Water Use (Gals / Row)	Average Water Application (Gals/ Tree /Day)	Av. Efficiency (Timed vs. Control)	Water Savings (Control vs. Timed)
Grower: Timed, Cyclic	26,025	1.035	0.372	269%
Sensor: Setpoint Control	9,683	0.385		

Conclusions: It is apparent from these results that we can consistently achieve autonomous set-point irrigation scheduling within a commercial nursery operation, using the battery-operated nR5 wireless sensor node. In addition, this autonomous control was achieved remotely through the internet during the six-plus months of the study. Most importantly, we achieved significant water savings with this control in comparison to a very experienced, hands-on irrigation manager, and without affecting the growth of the trees with these reduced irrigation water applications. Additionally, other tangible benefits are resulting from these sensor networks (Chappell et al., 2012; Majsztrik et al., 2012), which will enhance the return on investment to growers in the near future.

Acknowledgement: The authors gratefully acknowledge support from the USDA-NIFA Specialty Crops Research Initiative; Award # 2009-51181-05768.

Literature Cited:

Bacci, L., P. Battista and B. Rapi. 2008. An Integrated Method for Irrigation Scheduling of Potted Plants. *Sci. Hortic.* 116:89-97.

Bunt, A. C. 1961. Some Physical Properties of Pot-Plant Composts and their Effect on Plant Growth. *Plant and Soil* 13:322-332.

Chappell, M. and M. van Iersel. 2012. Sensor Network Deployment and Implementation in Commercial Nurseries and Greenhouses. Irrigation Association. 4-5th November, 2012. Orlando, FL. 9p.

Fereres, E. D., A. Goldhamer and L. R. Parsons. 2003. Irrigation Water Management of Horticultural Crops. *HortScience* 38:1036-1042.

Kohanbash D., A. Valada and G. Kantor. 2011. Wireless Sensor Networks and Actionable Modeling for Intelligent Irrigation. *Amer. Soc. Agric. Biol. Eng.* 7-12th August, 2011. Louisville, KY. Paper #1111174. 7p.

Kohanbash, D., A Valada and G. Kantor. 2012. Irrigation Control Methods for Wireless Sensor Network. *Amer. Soc. Agric. Biol. Eng*. 29th July-1st August, 2012. Dallas, TX. Paper #121337112 . 8p.

Kohanbash, D. and G. Kantor, G. 2012. Irrigation Scheduling Software Development. Irrigation Association. 4-5th November, 2012. Orlando, FL. 7p.

Kantor, G., D. Kohanbash, and T. Martin. 2012. Next generation monitoring and control hardware development. Irrigation Association. 4-5th November, 2012. Orlando, FL. 8p.

Jones, H. G. 2008. Irrigation Scheduling - Comparison of Soil, Plant and Atmosphere Monitoring Approaches. *Acta Hort*. 792: 391-403.

Lea-Cox, J. D., D. S. Ross and K. M. Teffeau. 2001. A Water And Nutrient Management Planning Process For Container Nursery And Greenhouse Production Systems In Maryland. *J. Environ. Hort.* 19:230-236.

Lea-Cox, J. D., A. G. Ristvey, D. S. Ross and G. F. Kantor. 2009. Deployment of Wireless Sensor Networks for Irrigation and Nutrient Management in Nursery and Greenhouse Operations. *Proc. Southern Nursery Assoc. Res. Conf.* 54: 28-34.

Lea-Cox, J. D., G. F. Kantor, W. L. Bauerle, M. W. van Iersel, C. Campbell, T. L. Bauerle, E. Lichtenberg, D. King, R. Bauer, L. Bissey & T. Martin. 2011. SCRI-MINDS - Precision Irrigation and Nutrient Management in Nursery, Greenhouse and Green Roof Systems: Year 2 Report. Available from <http://www.smart-farms.net/impacts> Accessed 09/30/2012.

Lea-Cox, J. D. 2012. Using Wireless Sensor Networks for Precision Irrigation Scheduling. Chapter 12. *In:* Problems, Perspectives and Challenges of Agricultural Water Management. M. Kumar (Ed.) InTech Press. Rijeka, Croatia. pp. 233-258. http://www.intechopen.com

Majsztrik, J. C., E. Lichtenberg, and J. D. Lea-Cox. 2012. A National Perspective on Irrigation trends and Sensor Network adoption in Ornamental Nursery and Greenhouse Operations. Irrigation Association. 4-5th November, 2012. Orlando, FL. 7p.

Majsztrik, J. C., A. G. Ristvey, and J. D. Lea-Cox. 2011. Water and Nutrient Management in the Production of Container-Grown Ornamentals. *Hort. Rev.* 38:253-296.

Ross, D. S., J. D. Lea-Cox and K. M.Teffeau. 2001. The Importance of Water in the Nutrient Management Process. *Proc. Southern Nursery Assoc. Res. Conf.* 46:588-591.

Van Iersel, M. 2012. Integrating Soil Moisture and Other Sensors for Precision Irrigation. Irrigation Association. 4-5th November, 2012. Orlando, FL. 14p.