

SCRI-MINDS: Managing Irrigation and Nutrients with Distributed Sensing

Developing Advanced Wireless Sensor Networks for Automated Irrigation of Intensive Specialty Crops

As a Coordinated Agricultural Specialty Crops Research Initiative Project (SCRI-CAP), we have developed and commercialized wireless sensor network systems that are capable of supporting the intensive production system requirements (complexities) of field nurseries, container nurseries, greenhouse operations and green roof systems.

The primary goals of the project were to:

1. Provide an integrative and mechanistic understanding of plant water requirements for intensive ornamental (specialty crop) production systems, spanning from the micro-scale (e.g. plant level) to the macro-scale (e.g. farms) ;
2. Improve irrigation water and nutrient (fertilizer) efficiency, optimize plant growth and quality, and minimize the environmental impacts of production practices;
3. Quantify private and public economic benefits of using sensor networks for improving production practices, identify cost and benefits to the industry and society, as well as barriers to the adoption of sensor network technology by specialty crop producers.

Our project engaged nursery, greenhouse and green roof collaborators on a day-to-day basis, to ensure that the next generation of hardware and software, developed by the engineering and commercial partners in the project (Carnegie Mellon, Decagon Devices and Antir Software) had the maximal utility and practical benefits required for intensive specialty crop producers. We integrated our specific project goals (below) across scales of production, by using small and large test sites in commercial operations. This allowed us to take a systems approach to understand the complexity of nursery, greenhouse, and green roof irrigation management decisions

Yearly project reports that including details of the progress, outputs and impacts can be accessed at the project website at <http://smart-farms.net/impacts>

A knowledge Center that includes many learning modules on various topics can be accessed from <http://smart-farms.org>

Background

Optimum management of global water resources presents one of the most critical challenges of the 21st century. Drought, population growth, increased urbanization, ground water overdraft and over-allocation of available surface water all contribute to fresh water shortages here in the United States.

- Agriculture is the greatest consumptive user of water in the US, and in many regions agricultural water use cannot be sustained. Irrigation accounts for 62% of freshwater (surface and ground water) use in the United States (Kenny et al., 2009).
- More than 55.4 million acres of land were irrigated in the United States in 2013, of which 72% were irrigated by sprinkler and micro-irrigation systems (USDA-NASS, 2014)
- The issues of water scarcity and water security were highlighted in recommendations by the Water Working group of the nation's Land-Grant Institutions to the US Department of Agriculture in August 2014, entitled "National Initiative on the Improvement of US Water Security."

Water availability and quality are important issues throughout much of the US. Although the severe drought in California and Western US gets most of the attention, it seems that there is always some part of the country that faces drought. In other places, such as Florida and the Chesapeake Bay area, water quality issues are a major concern. These issues affect agriculture, including the nursery and greenhouse industry. One of the challenges agriculture needs to address is how to decrease fresh water use and minimize the negative environmental impacts of production practices.

Global Results:

- The SCRI-MINDS project has developed advanced wireless sensor control technology and software to apply irrigation water based on daily plant requirements. Most importantly, this technology is affordable, easy to install and provides information that can be readily used by farmer to improve / automate daily irrigation management decisions with minimal management time.
- This wireless sensor control (WSC) system is now commercially-available as the PlantPoint™ system through one of the SCRI-MINDS project partners (Decagon Devices Inc., Pullman, WA).
- Additionally, the SCRI-MINDS project developed advanced monitoring and control software that extends the capability of the PlantPoint™ systems. This software is commercially available from Mayim, LLC (Pittsburgh, PA).

The SCRI-MINDS project has demonstrated that wireless sensor network control systems can provide specialty crop producers with the following benefits:

- A. Provide Farmers with their Own Real-time Information:** Sensor networks provide farmers soil moisture and environmental conditions for their own farm, via smartphone or any device that can access the internet. This provides farmers with information they trust and act upon. We have learned that most farmers make much better irrigation management decisions because they have access to their own information (Lea-Cox et al, 2013).
- B. Precision Control of Irrigation Water Applications:** We have shown through our research that we can achieve between a 40 and 70% reduction in irrigation water applications with sensor-based set-point irrigation control. For one of our growers, an average 50% reduction in irrigation saved over 43 million gallons of water, and \$6,500 in pumping costs in 2012. In the central valley of California, where water costs are typically \$750 / acre foot, the net cost of this 43M gallons of water would have been at least \$100,000, without accounting for additional pumping, plant growth or other economic benefits. In this case, the return on investment for the entire sensor network (\$48,000) would have been less than 4 months (Belayneh et al, 2013).
- C. Advances in Model-Based (Predictive) Irrigation Control:** We have demonstrated that model-based irrigation control (MAESTRA, Bauerle et al., 2014) can be as reliable as sensor set-point control. Predictive model-based irrigation offers a scalable, economic alternative to sensing substrate moisture. To simplify model-based irrigation applications on farms, physiological studies have shown that only two measured physiological parameters (g_0 and g_1) can maintain >90% transpiration prediction accuracy among genotypes or species (irrigation functional groups). Moreover, g_0 (as a single measured parameter) is the most influential parameter for predicting species-specific transpiration, is very easy to measure, and measured values provide more accurate model estimates of transpiration than linear extrapolation of the photosynthesis-stomatal conductance relationship.

- D. **Impact on Water Availability:** For most producers, the cost of water is very low compared to other variable costs, such as labor. However, most producers are limited by the capacity of their well, or by the time it takes to irrigate. Water availability and irrigation time is often the major constraint on the amount of land under production. One ornamental grower installed an additional 30-acre production block in 2013 based on the amount of water he saved using sensor-based irrigation.
- E. **Increased Crop Yields and Quality:** The growers now have a tool to further refine their growing practices for increases in yield and quality. For example, Majsztrik et al., (2013) and Lichtenberg et al., (Irrigation Science, in review) demonstrated that more timely irrigation decisions through the use of sensor networks in greenhouse production increased the yield and quality of snapdragon (cut-flowers) by 30% depending on season and cultivar.
- F. **Reduction in Labor Costs, Risk Reduction:** The automation and control of irrigation control in many nurseries can have a large impact not only on water, nutrient use and disease management, but for many larger nurseries, it is likely to reduce the fixed costs of at least 1-2 full-time irrigation managers. For many ornamental growers, this would amount to between \$50,000 and \$75,000 per year. It is unlikely that these jobs would be lost, since lower-skill jobs (opening and closing valves) would be replaced by higher-skill jobs (monitoring and maintenance, data interpretation) of computer-controlled irrigation systems. With better information provided by sensor networks, irrigation managers are likely to make much better and more timely irrigation decisions, and translate that knowledge into better nutrient management results (e.g. by reduced leaching events)
- G. **Reductions in Nutrient Leaching:** Water moves fertilizer through the soil, so irrigation management is a key part of nutrient management. Excessive irrigation leaches fertilizer from the root zone and results in additional fertilizer use. Bayer et al., (2014) found that sensor-based irrigation techniques can greatly reduce the fertilizer leaching, cutting the required fertilizer applications by 50%. We have estimated that just in GA (where the study was conducted), this would save ornamental growers about \$10,000,000 per year in fertilizer costs. For farmers in Maryland and Florida, demonstrating reductions in nutrient use is a key part of complying with State-mandated nutrient management regulations. Reduction in leaching also reduces the runoff from herbicide, fungicide and systemic pesticide applications.
- H. **Reduction in Plant Growth Regulator Chemical Use:** Plant growth retardants (PGR's) are widely used in ornamental horticulture to control plant size. Research with poinsettias (Alem et al., 2014) has shown that the use of a controlled water deficit is an effective, non-chemical alternative to the use of PGR's. Reducing the substrate water content reduces the stem elongation rate when plants get too tall. Using sensor-controlled irrigation systems, growers can maintain a lower substrate water content for as long as needed to get the amount of growth regulation needed. Additionally, the effect of water deficit quickly ends after substrate water content is increased again, in contrast to using PGR's. This makes the effect of water-deficits more predictable than using PGR's, which can have long-lasting and unpredictable effects on elongation rates. The use of non-chemical growth regulation can also be used for marketing purposes, since consumer concern over the use of agro-chemicals is steadily increasing.
- I. **Disease Management:** Chappell et al., (2013) showed that with sensor-based irrigation, disease-related losses with Gardenia were reduced from 30% to virtually zero, and the production cycle was shortened from 14 to 8 months, with consequent reductions in inputs (labor, fertilizer, fungicides etc.). Combined, this resulted in a 256% increase in annualized profit (Lichtenberg et al., 2013), with a payback period of less than 1 month on the sensor network (approximately \$6,000). Although perhaps unusual, this study illustrates the compounded economic benefit of increases in efficiency, yield and disease reduction as well as increased turnover of production space.

- J. **Overall Environmental benefits:** We projected environmental benefits with a variety of scenarios for ornamental growers in the US (Majsztrik, Price and King, 2013). For example, using a 50% industry adoption rate in the nursery industry alone, a 50% reduction in water would save enough water for 400,000 households a year, reduced energy usage equivalent to removing 7,500 cars annually, and savings of 282,000 kg of nitrogen and 182,000 kg of phosphorus from entering the environment (Majsztrik et al., 2013). Adoption of the technology in the vegetable, fruit and nut industry would further increase these societal benefits.
- K. **Weather Station (Microclimatic) Data:** Typically we install a “weather station” node that is connected to a number of weather sensors. Although the data are useful to growers to precisely measure their microclimatic conditions on the farm, it is the additional information that the Sensorweb software can calculate that provides very powerful information for farmers (Lea-Cox et al., 2012). This integrated data includes “Degree Days,” used for calculating insect emergence rates, and hence timing and targeting pesticide applications appropriately. Chilling hours (predicting bud and flower emergence for fruit growers) can also be easily tracked, enhancing pollination decisions. Leaf wetness measurements can be used to predict disease outbreaks. This information, combined with real-time wind speed and direction data can significantly increase the efficacy of agrochemical sprays, to help avoid costly mistakes. Many additional predictive models are being integrated into the software over time, adding to the value of the information that sensor networks provides farmers, to improve timing, resource use efficiency, productivity and ultimately profitability.
- L. **Extending our Impact to Food Crops; Frost Warnings:** Strawberry production nationally is a \$2.7B dollar industry, with over 70% of the production in Florida and California, where water and nutrient runoff are major concerns. Current research at the University of Maryland is funded by a grant from the Walmart National Sustainable Strawberry Initiative. We are implementing sensor networks in strawberry production, not only to reduce irrigation water and nutrient applications, but also to investigate the utility of sensor networks for frost protection. Since we can sense both leaf and flower temperatures in the canopy, the PlantPoint™ system can not only send out text or voicemail alerts to growers on their phones, but irrigation systems can also be automated for frost protection, starting water applications only when needed.
- M. **Building Capacity:** The SCRI-MINDS project has supported and benefited from the research of 4 international visiting scientists, 4 post-doctoral research associates, 11 PhD, 4 MS graduate students and 9 undergraduate research interns. Many of the post-doctoral and PhD students are now in academic or research positions at Universities and companies in the US and Korea.