Precision irrigation: How and why?

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Water availability and quality are important issues throughout much of the US. Although the severe drought in California 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, the Chesapeake Bay and Puget Sound areas, water quality runoff issues are a major concern. These issues affect agriculture, including the greenhouse industry. One of the challenges our industry will need to address is to decrease water use and minimize any negative environmental impact.

For the last decade, we have been working on ways to help the greenhouse industry reach those goals. We have focused on the use of sensors to provide growers with the information they need to make better irrigation decisions. We have also developed hardware and software that helps growers automate irrigation based on that information. And we are working on ways to help growers make more informed nutrient management decisions.

Our basic approach is pretty simple: we use soil moisture sensors to measure how wet the substrate is. When the substrate gets too dry, the crop is automatically irrigated. This results in on-demand irrigation: when crops use a lot of water, they automatically get irrigated more frequently.

Implementing this irrigation approach is fairly simple in many greenhouses. If you have an advanced environmental control system you probably can already integrate soil moisture sensors into this system. The next step would be to monitor substrate water content data to see how your current irrigation practices affect substrate water content. With that information at your fingertips, you can probably see how you could do things differently. And once you are comfortable with the data, you can take the next step and have the environmental controller trigger irrigation automatically based on substrate water content readings. For smaller greenhouses, which often have very simple environmental controllers, and for nurseries, we have developed a different solution: stand-alone wireless sensor networks.

As part of our work on this project, we have done trials in university greenhouses and in commercial greenhouses and nurseries. Especially our work with commercial growers has given us many insights into the potential benefits growers can get out of precision irrigation. The following sections provide a description of the hardware and software we developed, as well as some of the highlights of what this technology can do for growers.
Wireless sensor networks

Wireless sensor networks typically consist of multiple ‘nodes’ with multiple sensors connected to each node. In our case, we use sensors that can measure soil moisture, water pressure, flow rate, or a range of weather variables (light, temperature, wind, humidity, etc.). The nodes have a radio built-in for two-way communication with a computer. The computer runs the software (or graphical user interface) that is used to control the setup of the entire network and to configure irrigation parameters (Fig. 1). Growers can use the information from these sensors to decide how they want to manage the irrigation of different crops. These decisions can be programmed into the graphical user interface (Fig. 1). Although our prototype nodes had relays built in that could be used to automatically open and close irrigation valves, the commercial system that will be released soon has a different configuration.

Figure 1. The basic layout of a wireless network system.

Fig. 2. The commercial wireless network system will have three different nodes. Left to right: a gateway, a control, and two monitoring nodes. Photo courtesy of Decagon Devices.
Decagon Devices, our commercial partner, will commercialize the PlantPoint™ system. This system consists of three different types of nodes, which look similar, but have distinctly different functions: monitoring nodes, control nodes, and gateway nodes (Fig. 2). Since the nodes are powered by batteries, they can be placed in production areas where power is not available.

Monitoring nodes can be used to connect up to five sensors. Control nodes accommodate only a few sensors, but can be used to control up to four separate irrigation zones. The gateway node relays information between the control nodes, monitoring nodes, and the SmartBase station (Fig. 3). The SmartBase generates a website that can be accessed on-line. This website serves as the graphical use interface.

The website can be customized with a map of a specific greenhouse, nursery or farm and detailed information from each of the nodes can be seen in graphs that summarize the most important information from each node (Fig. 4). The data is presented in a way that helps growers use that information to make better informed decisions about irrigation scheduling. The website is also used to configure the irrigation control nodes. Growers can program whether they want to irrigate based on a set schedule, based on substrate water content, or other parameter. The hardware and software are designed for maximum flexibility to accommodate the needs of different growing operations. One crucial feature is scalability: growers can start with a small system and gradually expand that system over time. This will hopefully encourage growers to adopt this new technology, starting with a small system to determine whether it is cost-effective and, if so, to scale up. The system is expected to be released in Fall 2015.

Fig. 2. Diagram highlighting the three types of nodes: monitoring, control, and gateway nodes.

Fig. 3. The SmartBase appliance is built on an industrial computing motherboard and has no moving parts. The SmartBase generates a webpage that can be accessed by internet-enabled devices, such as computers, tablets, or smartphones. Photo courtesy of Decagon Devices.

Fig. 4. The graphical user interface of the PlantPoint™ system. Photo courtesy of Decagon Devices.
Benefits of wireless sensor networks for irrigation management

Provide growers with real-time information: Sensor networks provide growers soil moisture and environmental conditions for their own greenhouse or nursery. Since the data can be seen on-line, access to this information is easy. This provides growers with information they trust and can act upon. We have learned that most growers make much better irrigation management decisions once they have access to data collected in their own operation. Seeing the impact that your irrigation decisions have on substrate water content makes it easy to improve on standard practices.

Precision Control of Irrigation: We have shown through our research that we can achieve between a 40 and 70% reduction in irrigation water applications with soil moisture sensor-based irrigation control. Although reductions vary from operation to operation, because all growers manage irrigation differently, we have consistently seen large reductions in irrigation water use. For one of our nursery growers, a 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 43 million 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 $48,000 sensor network would have been less than 4 months.

Impact on Water Availability: For most growers, the cost of water is low compared to other variable costs, such as labor. However, some operations are limited by the capacity of their well or pump, or by the time it takes to irrigate all crops. Water availability and irrigation time can limit the amount of plants that can be grown. One nursery grower was able to install an additional 30-acre tree production area, simply based on the amount of water he saved elsewhere using sensor-based irrigation.

Increased Yields and Quality: Growers can use these sensors as a tool to refine their growing practices for increases in yield and quality. For example, a snapdragon cut flower grower was able to make more timely irrigation decisions through the use of sensor networks in his greenhouse production. Since these plants were grown in a recycling hydroponics system, water savings were not much of a concern. But better irrigation management increased the yield and quality of snapdragon cut-flowers by 30% depending on season and cultivar. This clearly shows that the benefits of precision irrigation go well beyond just water savings.

Fig. 5. Flowers By Bauers & Greenhouses was able to increase the yield and improve the quality of their cut snapdragons by switching over to precision irrigation. Picture courtesy of Edwin Remsberg/University of Maryland.
**Risk and Labor Costs Reduction:** The automation and control of irrigation in many greenhouses and nurseries can have a large impact not only on water, nutrient use and disease management, but for many larger operations, it is likely to reduce the fixed costs of at least 1-2 full-time irrigation managers. For many 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, hand-watering) 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 (for example by reducing unneeded leaching).

**Reductions in Nutrient Leaching:** Water moves fertilizer through the soil or substrate, so irrigation management is a key part of nutrient management. Excessive irrigation leaches fertilizer from the substrate. The leaching of fertilizer from the substrate may than require additional fertilizer applications. We found that sensor-based irrigation control can greatly reduce fertilizer leaching, cutting the required fertilizer applications by 50%. We have estimated that just in Georgia, this could save ornamental growers about $10,000,000 per year in fertilizer costs. Fertilizer savings can be achieved regardless of whether water-soluble or controlled-release fertilizer is used. When using water-soluble fertilizer, less irrigation will automatically reduce fertilizer applications. When controlled-release fertilizers are used, better irrigation management will reduce the amount of fertilizer that is leached and thus reduce the need for additional fertilizer applications. Reduced leaching can also help growers meet environmental regulations. For example, growers in Maryland and Florida need to demonstrate reductions in nutrient use as a key part of complying with state-mandated nutrient management regulations. A reduction in leaching also reduces the runoff from herbicide, fungicide and systemic pesticide applications.

**An Alternative to Plant Growth Regulators:** Plant growth regulators are widely used in the greenhouse industry to control plant size. Research with poinsettias has shown that sensor-controlled irrigation can be used as a non-chemical alternative to the use of PGRs. Sensor controlled irrigation can be used to expose plants to a controlled water deficit. This can be used to reduce 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. 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.

![Fig. 6. The different size poinsettias were produced by imposing different durations of precisely controlled drought. This is a non-chemical alternative to the use of growth regulators.](image)
**Disease Management:** Sensor-based irrigation decreased disease-related shrinkage in Gardenia from 30% to virtually zero. On top of that, the production cycle was shortened from 14 to 8 months, reducing the required inputs (labor, fertilizer, fungicides etc.). Combined, this resulted in a 2.5-fold increase in annualized profit, with a payback period of less than one month on the sensor network (approximately $6,000). Although perhaps unusual, this study illustrates the compounded economic benefits of increases in efficiency, yield and disease reduction, as well as increased turnover of production space.

**Overall Environmental Benefits:** We projected environmental benefits with a variety of scenarios for ornamental growers in the US. For example, using a 50% industry adoption rate in the ornamental industry alone, a 50% reduction in water would save enough water for 400,000 households a year, reduce energy usage equivalent to removing 7,500 cars annually, and prevent 620,000 lbs. of nitrogen and 400,000 lbs. of phosphorus from entering the environment. So the benefits of this technology go well beyond individual growers. Society-at-large benefits as well. Because of the societal benefits of the technology, it is likely that federal cost share programs could be used to help pay for the on-farm installation of sensor networks. We already have talked to the National Resources Conservation Service about this and their environmental quality incentives program (EQIP) will likely offer opportunities for matching funds.

Perhaps the main thing we have learned over the last decade is that we can never know what to expect. The growers we have worked with have taken this technology and at times used it in ways we never expected. As a result, predicting all possible benefits from the technology is not possible. It will be exciting to see the technology adoption by the industry and to see how this will be used. But one thing has become clear: growers quickly adapt to the technology and find ways to maximize their benefits.

Acknowledgements: our work was part of a much larger project that included too many people to mention here. But to learn more about what we have done, please visit the project website at www.smart-farms.net. To help growers learn more about wireless sensor networks, we have developed an on-line learning center at www.smart-farms.org. Our work has been sponsored by the Fred C. Gloeckner Foundation, the American Floral Endowment, the Horticultural Research Institute, and USDA–NIFA Specialty Crops Research Initiative Award #2009-51181-05768.