Costs and Benefits of Wireless Sensor Networks:

How a sensor network might benefit your operation

Introduction- What is a wireless sensor network?

A wireless sensor network is a combination of hardware and software that can provide real-time information about soil moisture and other factors at your operation (Figure 1). Hardware includes sensors that can measure things like soil moisture, air temperature, relative humidity, solar radiation, electrical conductivity (salt) levels, and leaf wetness. These environmental sensors (see the online learning module - All About Sensors) are then connected to a datalogger or "node" which collects, stores, and transmits the information collected from sensors.

This node then wirelessly transmits this information automatically to a base station, similar to sending a text message via a phone. The base station receives this information from all of the nodes at your operation and stores it permanently on your computer's hard drive. You can quickly access real time or historic sensor information through software that is installed on your computer.

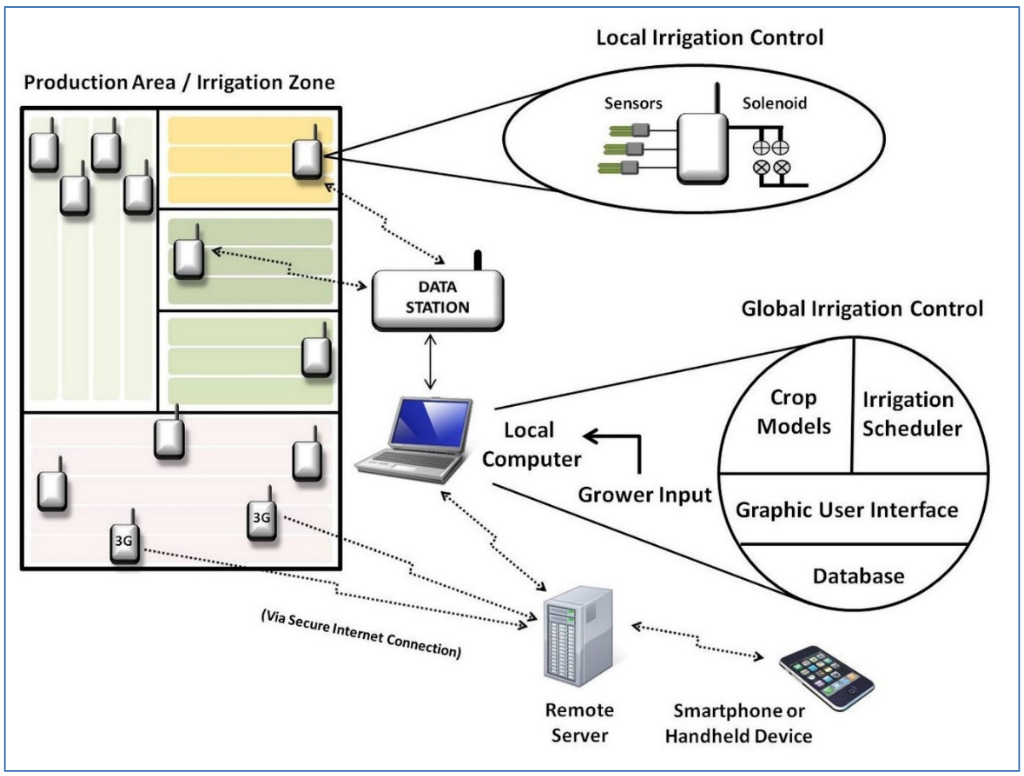

Figure 1. Schematic of wireless sensor network, showing sensors, nodes, and base station

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Majsztrik, J., E. Lichtenberg, and M. Saavoss. 2014. Costs and benefits of wireless sensor networks: How a sensor network might benefit your operation. *In*: Managing Irrigation through Distributed Networks Knowledge Center, M. Chappell, P. Thomas, and J.D. Lea-Cox (Eds.). Published online at: https://myelms.umd.edu/courses/1110342 18p.

Under what conditions does a wireless sensor network make sense?

The Decagon wireless sensor network system (http://www.decagon.com/products/soils/) that was developed and tested as part of the SCRI-MINDS project, and which has been commercially released as the Plant Point® system, has a number of advantages. A sensor network can start out small, and be expanded as needed just by adding additional nodes and sensors (it is scalable).

Also, sensors and nodes can be easily and quickly moved from one location to another (it is reconfigurable). If you have a problem situation in your operation that you would like to investigate, you can install the system, and monitor it for a period of time (weeks, months, years). When you have answered the questions that you were asking, you can then move it to another area/crop.

There are a number of factors that will impact whether a wireless irrigation system will be profitable at your operation. Some of these factors are discussed below.

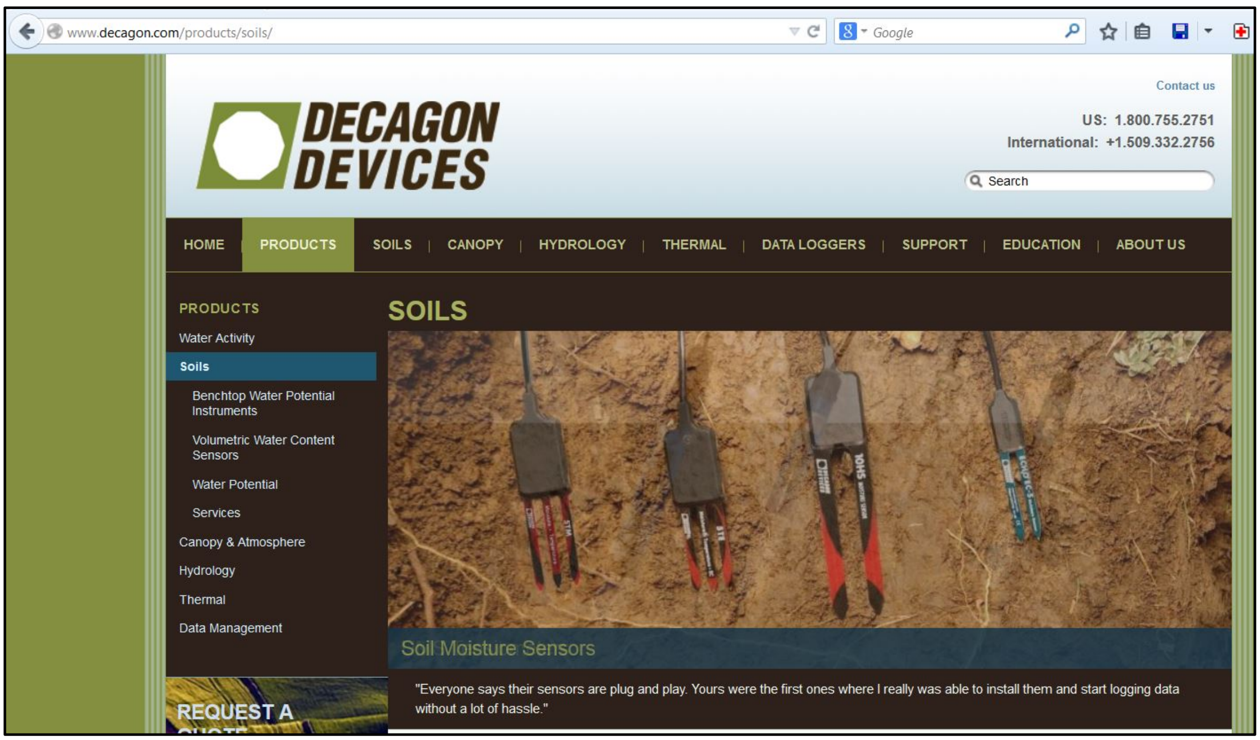

Figure 2. Decagon Devices, Inc webpage, with information on their latest sensors and nodes.

Majsztrik, J., E. Lichtenberg, and M. Saavoss. 2014. Costs and benefits of wireless sensor networks: How a sensor network might benefit your operation. *In*: Managing Irrigation through Distributed Networks Knowledge Center, M. Chappell, P. Thomas, and J.D. Lea-Cox (Eds.). Published online at: https://myelms.umd.edu/courses/1110342 18p.

The overall size of your operation: The larger the operation, the more likely you will benefit. This is especially true if you have one or more people who monitor and/or schedule irrigations on a daily basis. As operation size/complexity increases, more time is devoted to making irrigation decisions, which can be greatly reduced with sensor networks.

Figure 3. Larger operation sizes are more likely to benefit from sensors.

The percent of your revenue from ornamental production: The higher the percentage of your income from high value crops, the more likely you will benefit from implementing this technology. Since sensors have a cost associated with them (money, time to learn, labor to set up and maintain), the more you are able to use this information to change practices at your operation, the more likely you are to benefit. If for example, your main revenue is from corn and soybean production, but you also grow some bedding plants in the spring, it is unlikely that sensor networks would provide enough benefits to justify their cost. Whereas if your main income was from ornamental, fruit or vegetable production, there is a greater chance that a sensor network could help you become more profitable.

Figure 4. Sensor networks can help identify problems in certain areas or certain species.

Problem areas or problem plants: Some plants are difficult to irrigate because of slow growth rates or they are prone to root disease. Some areas in your operation may be either too dry or too wet due to differences in soil type, topography, location etc. making it more challenging to discern proper irrigation practices and grow plants there.

Large areas of plants that are irrigated similarly: This may be by design (you grow a lot of pansies), or due to constraints (I am space limited). You may have a number of different species or container sizes in the same irrigation zone.

Figure 5. Large areas of the same or similar plants would likely benefit from sensor networks.

Sensors can help you determine and confirm which plants you should be monitoring, and you can then base irrigation decisions on those "indicator species." For example, sensors can help you determine which plants dry out the fastest, and therefore should be monitored so that irrigation events can be more accurately scheduled for that zone.

Labor is costly – Installing sensors in a block provides continuous data, instead of just subjective spot checks (feeling the soil or lifting the container). Continuous soil moisture data, once correlated to the plant species can then be used to turn the irrigation on and off, manually or automatically, exactly when it is needed. Typically at least 3-4 plants are monitored and an average "set-point" is used to make this irrigation control decision, for safety. But by allowing the sensor network to control irrigation you save the expense of having someone perform these tasks, in addition to many other benefits we will discuss.

More importantly, we have found that by taking advantage of sensor information and the automated irrigation capability of the Plant Point™ stystem not only do we see savings of about 50% water on average, but irrigation water is applied preciscely when the plant actually needs it. That typcially means less water stress, faster growth rates, and improved crop quality.

How can a sensor network save me money?

There are a number of ways that we have found that sensor systems can save you money. Where you save money, and how much, depends on a number of factors. We will discuss some of these examples in the following sections. The next learning module ([return on investment]) will look at overall payback, and allows you to enter specific information for your operation, using a spreadsheet file that you can download.

Some of the biggest savings that we have seen related to more timely irrigation decisions is tied to irrigating plants exactly when they need it, and reducing over-irrigation (reducing nutrient loss, and disease incidence).

For maintaining optimum plant growth, a good analogy to think of is driving a car on the highway. If you are using cruise control at 65mph, the car continues to move at a steady speed, minimizing fuel consumption. This is like irrigating your plants exactly as much as they need, when they need it. They can continue to grow at maximum speed. Now imagine you are driving along the highway and you keep stepping on the brake, or taking your foot off of the gas. Since you can't go any faster than the speed limit (maximum plant growth), you are lengthening the time it takes you to get to your destination (saleable size). If you are letting plants get too dry, or keeping them too wet, it is like you are stepping on the brake. It takes plants time to adjust to changing conditions, so they are not growing at maximum speed. Sensors help plants achieve maximum growth rate by providing them with ideal moisture conditions (assuming the set points are correct, which you can learn about in other modules).

To illustrate this point, a grower involved with our project was having a difficult time growing Gardenias (*Gardenia jasminoides*). Their typical production time was 14 months. They installed a sensor system, and production time was reduced to 9 months.

The experiment was run a second time, but with very different results. Instead of 9 months, the plants were ready to sell after only 5 months, as they started this crop in the spring instead of the previous fall (Figure 6).

The best part is these results were achieved by using LESS water! More details and a discussion of the analysis can be found under additional resources at the end of this module.

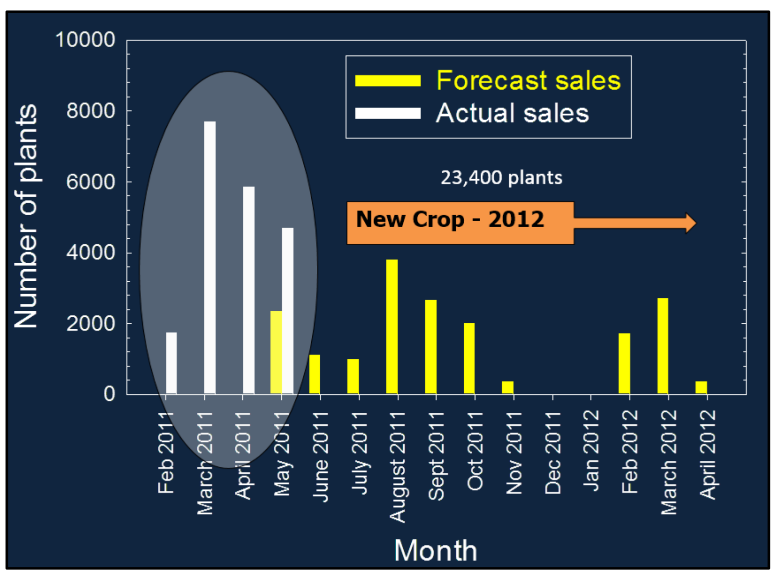

Figure 6. Acutal plant sales vs forecasted plant sales for Gardenias. Plants were ready to be sold in 5 months using sensor networks, as opposed to the typical 14 months for this operation.

Energy / water / fertilizer costs-savings

We have found that most ornamental greenhouse and container-nursery growers tend to over water plants. This makes sense because containers can dry out very quickly, so making sure that plants have enough water to make it until the next irrigation cycle is important. It is also very difficult to adjust plant water needs when weather (especially temperature and wind) conditions change every day. Ideally, applied water will just start to leach out the bottom of the container when the irrigation is turned off, and the root zone is fully wetted. The reality is that containers are most often over irrigated to make sure they are have reached container capacity. By cutting back on irrigation, there are a number of benefits (besides the increased growth rates discussed above).

Figure 7. Sensor networks can conserve water resources.

Using your irrigation pumps less keeps more water in the ground or in your pond and lowers your water utility bills. This also helps your pump last longer, and require less maintenance. Additionally, it saves on electricity and/or diesel costs. This impacts your bottom line, and the environment.

Reducing leaching also helps stretch your fertilizer dollars. It doesn't matter if you are using soluble or slow release (also called controlled release) fertilizers. Keeping water in the root zone, without leaching it, also keeps the fertilizer in the root zone. The bottom line is that the longer water and fertilizer stays in the root zone, the more of it is available for plant uptake and growth. If you fertigate, it is possible that you can cut down on your fertigation frequency or application rate, or typically both. Increased fertilizer use efficiency (the percent of fertilizer taken up by the plant) also reduces your impact on the environment (both groundwater leaching and runoff) and most importantly saves considerable amounts of money.

Figure 8. Sensor networks can reduce fertilzer costs.

Increasing Land Area under Production / Increasing Efficiency / Troubleshooting Issues

Saving water may also mean that you can expand your operation. If you can reduce your irrigation volumes by 50% or more (which we have seen in many of the operations that we have wireless sensor networks installed), you can then use that water for other things, including expanding your operation if you are water limited, or avoiding the expense of drilling another well.

Instead of traveling to each irrigation block to determine irrigation needs, real-time soil moisture can be checked from an office computer, or remotely with a smart phone at any time. This saves time, and increases operational efficiency. The software can also be easily configured to send out alerts if there is a problem (bad sensor, low soil moisture, irrigation was not triggered etc.).

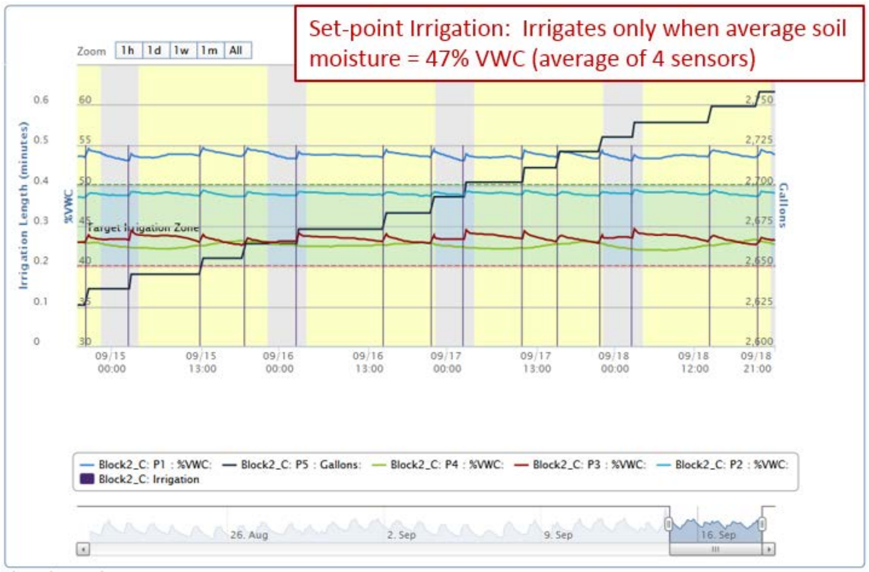

Figure 9. Software provides real-time data from sensors.

Further increasing operational efficiency, control nodes are available that can not only monitor and alert you to specific soil moisture conditions or equipment problems, but also turn irrigation on and off as needed, using average soil moisture data, as described above. You determine the set point (volumetric water content or VWC) that the irrigation is triggered, and when the average sensor reading is brought back above that threshold, the irrigation solenoid is automatically switched off by the control node.

Sensors can also help troubleshoot problems at your operation, further saving you time. If there is a particular plant that is difficult to grow, or a particular location that is challenging to grow plants in, (Ex. sensitive to overwatering, or a soil is particularly sandy) sensors have been found to be an effective way to help diagnose and fix the problem. For example, by placing moisture sensors in areas of a field which are sandier and prone to leaching, irrigation can be correctly determined and applied to that area.

Time is money! How much is your time worth?

Although it is a cliché, it is also true. Labor is a large portion of the expense for many horticultural operations. The time that you or your employees spend tending to a crop increases the cost to produce it. People that make irrigation decisions are typically in higher paying positions; the owner puts a lot of trust in this person to make the right decisions on a daily basis.

Figure 10. Sensors may be able to reduce labor expenses at an operation.

There are two main ways that a sensor system can save you time (and money): managing irrigation, and monitoring moisture status. Reducing the time that it takes to make and manage irrigation decisions frees up time for these employees. Sensor networks reduce the need for workers to visit every block, every day in the operation, to determine if irrigation needs to be applied; then to adjust the controller, or manually turn the irrigation on and off. Unfortunately, very often irrigation decisions are performed by setting a time-clock, without actually determining whether the plants in the block actually need it.

How often these steps are completed and the time it takes to do them will impact your cost savings with sensor networks. Sensor networks do this automatically based on the set points you determine, saving labor while irrigating the crop at the right time, with the correct amount of water. In other words, sensors take much of the guess work out of irrigation frequency and timing. Sensors can also free up time to focus on different tasks (IPM scouting, irrigation maintenance, training etc.). Sensors that measure electrical conductivity (EC) can also help with fertilization decisions, allowing for continuous monitoring of fertilizer availability in the root zone and eliminating the need for manual pour-through evaluations. Since sensors may reduce disease incidence, you may also save considerable amounts of money and time on fungicide applications.

During one of our studies, someone forgot to come in on the weekend to water the plants that were being controlled by the grower (but they were still monitored), which severely water stressed the crop. The plants that the researchers were monitoring and controlling did not have the same "near death experience". Unlike your employees, sensors never forget to come in on the weekend or fail to turn irrigation on or off, so there is less of a risk to your crop. If there is a problem, the system can also send you an alert, so it can be dealt with in a timely manner.

Disease Reduction

Figure 11. Better irrigation practices may lead to additional benefits such as reduced fertilizer use and reduced disease incidence.

Reducing irrigation does not just save on pumping and other water related costs. We have found that growers have gained additional benefits applying irrigation that more closely matches plant daily requirements. As mentioned previously, sensor networks have reduced irrigation application volumes by 50% or more compared with best management practices. Excess irrigation can produce a number of unintended consequences. Improper irrigation frequency and duration can lead to nutrient loss through leaching. More efficient irrigation also leads to reduced disease incidence since plants are not over or under irrigated, which can lead to stress, and infection. Roots are also able to spread more to find water throughout the container, and any residual water inside the container is reduced, which creates a healthier root system. Less water in the container leads to improved aeration, and more oxygen for the roots. All of these factors lead to a healthier plant, and an increased plant growth, which can lead to a shorter production period and a healthier, higher quality plant overall. You may also be able to save money through less frequent fungicide applications (both materials and labor).

Manipulating growth

If plants have reached a saleable height (or diameter for trees), sensors can help maintain them at that size until they are ready for sale. This can be accomplished through set point control which keeps the moisture level in the container or root zone at a level that minimizes growth, while maintaining plant quality. Better irrigation control can also lead to reduced vegetative growth and denser canopy development, which reduces pruning requirements to maintain plant size and shape.

As part of the SCRI-MINDS project, we have shown that sensor networks are able to manipulate plant growth, similar to plant growth regulators (PGRs). In a study with Poinsettias, researchers were able to control the height and overall appearance of poinsettias using water deficits instead of PGRs. This saves the labor and expense of application, but also reduces the environmental impact of your operation. More information about this study can be found at the end of this module in: Alem and van Iersel, 2014.

Monitoring EC

Sensors (such as the Decagon GS3) are capable of monitoring EC (electrical conductivity) levels in soils and substrates. Monitoring substrate EC is important for a number of reasons. If plants are being grown in areas with high salt concentrations in irrigation water, sensors can help guide water applications (frequency and duration of irrigation) for leaching salts out of the substrate/soil to minimize plant damage.

Figure 12. Electrical conductivity (EC) sensors can help determine when controlled release fertilzers have run out.

Sensors can also be used to determine when slow release fertilizers (SRF) (also called controlled release fertilizers; for example Nutricote®, Florikote®, polyon®), have been depleted. Using EC sensors, growers can monitor increases in soluble nutrients during summer as higher temperatures cause higher nutrient release rates. Containers can be monitored to reduce leaching, so fertilizers remain in the container or root zone, or irrigation can be applied to leach fertilizers so they do not cause damage to the roots. If SRF's have been exhausted in the late summer or fall, the EC data will indicate reduced available nutrient levels, and the grower could switch over to fertigation (only recommended for spray stakes or other precision irrigation systems), or perhaps a reapplication of SRF to maintain growth.

In greenhouses or other situations where fertigation (continuous or discontinuous) is used, sensors can be used to help determine when and how much fertilizer should be applied through fertigation lines. By being able to continuously monitor salt levels, fertilizer can be applied when needed, reducing costs. If continuous fertigation is required, sensors can be used to determine if current rates are too high or low based on salt levels over time.

All of these scenarios help contribute to a reduction in fertilizer cost, which increases your profits.

Weather Station

We recommend installing a weather node at your operation, which is connected to a number of sensors that measure environmental data. These are typically air temperature, relative humidity, and vapor pressure deficit (VPD), photosynthetically active radiation (PAR), a rain gauge and an anemometer (wind speed and direction). You can learn more about weather stations in our learning module at https://myelms.umd.edu/courses/1110351

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 informing daily decisions.

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.

Figure 13. It is recommended that you install a weather station node at your opearation. It is invaluable for providing information about your micoclimate, and is used by the software to calculate a number of factors (degree days, chill hours, etc.).

Case studies

In order to give you a better understanding of how your operation might benefit from sensor networks, a few case studies are highlighted below. More details about these studies can be found in the referenced papers, or in other modules in this knowledge center.

Pot in Pot

Figure 14. Pot-in-pot production.

A large network was installed at a pot-in-pot operation as part of this project. The total cost of this 25-node network was $48,000 including installation, which was annualized over 3 years assuming a compound interest rate of 6%. We assumed 1/3 of the sensors and nodes would be replaced per annum starting in year 4. Annual savings (pumping, management costs etc. for this operation) was $20,300, enough to pay off principal and interest on a 6% loan in a little under 9 months. Looked at another way, those savings would be enough to pay off all initial outlays on equipment and installation (about $48,000) in a little over 2 years. Yearly net savings (irrigation savings - system cost) were $5,300 per year, a 37.5% increase in annual profit. Locations that had higher pumping costs (i.e. operations using deep wells) or paying more for water would realize greater savings and thus greater increases in profit. Full details about the experiment can be found in the article: Belayneh et al, 2013 at the end of this module.

Container Nursery

An eight node network was installed at a container operation at a total cost of $11,265. .
In this case, profits using sensor networks were increased by 146% compared with current practices, so that principal and interest on a 6% loan would be paid off in about 2 months. Details about this system can be found in the article: Lichtenberg et al., 2013 at the end of this module.

For both of these networks however, additional costs, such as the cost of installation, and the cost of commercial hardware and software development were not taken into account. A commercial control network would likely be about 40% higher in cost, without installation or maintenance. From these two examples, and others from our project, the type and magnitude of savings with sensor network are different for each operation, but we have consistently seen considerable returns on investment.

Getting Started

How many and the types of nodes and sensors you purchase is dependent on a number of factors such as the size of your operation, the diversity of the plants that you grow and how much of your revenue comes from higher value crops etc.

You can start with a small network (2-4 nodes), depending on the type of node and sensors you choose. You can use this network to evaluate the system, and decide if it benefits your operation. Based on our experience with a number of growers in a variety of situations (from continuous greenhouse production, to container, to pot in pot to field production) sensor networks have provided a number of benefits to growers.

After evaluating a system, you may want to expand your system, redeploy some nodes and sensors to another crop or field, or decide that is does not benefit you enough to keep it. If you decide to expand your system, the additional cost will be just for additional nodes and sensors, since the initial investment in the computer, base station and software can be used for these additional nodes as well. One of the benefits of sensor networks are that a node and sensors can be used to answer a specific question (for example, am I over irrigating this species), and then when enough information has been gathered to answer that question, that node can be redeployed elsewhere, adding value to the senor network purchase.

Scaling sensor networks

Since the same base station, software etc. can be used on any number of nodes, it is recommended that sensor networks should start out small, installing a few nodes at the operation. Starting small allows you to build confidence in the sensors, and how you use them to make decisions, while reducing your initial capital costs. Once you feel more comfortable with the data that the sensor networks provide, and your ability to use this information to make decisions (or setting up the node to control itself), you can expand your sensor network. Since nodes and sensors can easily be moved from one location to another, a small network can be reconfigured based on your needs.

Sensor Network Configurations.

There are many factors that determine the cost of a wireless system for your operation. The type and number of sensors and nodes you purchase, the layout of your farm, and the number of species and or areas you choose to sense will impact the number and type of sensors and nodes you purchase. Some example starter configurations are listed below. We will cover the potential returns on investment in the next module.

Tables 1 and 2 illustrate some of the possible sensor configurations for different scenarios. Table 1 shows some potential configurations for a "typical" weather station and a propagation house. These are the different sensors and nodes that can be used, along with the information that the sensors would provide. Table 2 shows a number of different sensor configurations that could be used in a variety of ornamental production settings. These tables are meant to give you an idea of what an installation might look like in these different types of settings, and would vary depending on your particular operation.

Table 1. Potential sensor and node configurations for propagation houses and weather stations.

Common Wireless Sensor Network Configurations By Operation Type

Operation Type	Monitoring Concentration	Irrigation Automation	Node Model	Sensor Model	Sensor Attributes	Sensors Per Monitored Zone	Nodes Per Monitored Zone
Propagation Houses	Temperature Relative Humidity Vapor Pressure Deficit Soil Moisture Leaf Wetness		EM50R Or EM50R (3G)	EC5 Or GS1	Smaller Sensing Area & Reduced Cost (Soil Moisture) Increased Durability (soil moisture)	4	2
				LWS	Leaf Wetness	4	
				VP3	Air Temp., Relative Humidity, Vapor Pressure Deficit	2	
Weather Station	Temperature Relative humidity Vapor pressure deficit Photosynthetically active radiation Leaf wetness Wind speed & direction Rain Quantity Grower degree days		EM50R Or EM50R (3G)	VP3	Air Temp., Relative Humidity, Vapor Pressure Deficit	1	1
				PAR	Photosynthetically active radiation	1	
				LWS	Leaf Wetness	1	
				Sonic Anemometer	Wind speed & direction	1	
				Rain Gauge	Rain Quantity	1	

Majsztrik, J., E. Lichtenberg, and M. Saavoss. 2014. Costs and benefits of wireless sensor networks: How a sensor network might benefit your operation. *In*: Managing Irrigation through Distributed Networks Knowledge Center, M. Chappell, P. Thomas, and J.D. Lea-Cox (Eds.). Published online at: https://myelms.umd.edu/courses/1110342 18p.

Table 2. Potential sensor and node configurations for a variety of operation types. Configurations are meant to illustrate potential sensor and node combinations, and the information that would be provided.

Common Wireless Sensor Network Configurations By Operation Type

Operation Type	Monitoring Concentration	Irrigation Automation	Node Model	Sensor Model	Sensor Attributes	Sensors Per Monitored Zone	Nodes Per Monitored Zone
Field Production Nursery (Soil) Nursery (Pot-In-Pot) Agronomic Orchard	Soil Moisture	✗	nM50 Or EM50G	10HS	Large Sensing Volume	5	1
				GS1	Increased Durability		
				EC5	Smaller Sensing Area & Reduced Cost		
Field Production Nursery (Soil) Nursery (Pot-In-Pot) Agronomic Orchard	Soil Moisture	✓	Or EM50G	10HS	Large Sensing Volume	5	1
				GS1	Increased Durability		
			nC24	EC5	Smaller Sensing Area & Reduced Cost		1
Container Production Greenhouse High Tunnel	Soil Moisture Electrical Conductivity Temperature Relative Humidity Vapor Pressure Deficit	✗	nM50 Or EM50G	10HS	Large Sensing Volume	6	2
				GS1	Increased Durability		
				EC5	Smaller Sensing Area & Reduced Cost		
				GS3	Electrical Conductivity, Substrate Temp., Substrate Moisture	2	
				VP3	Air Temp., Relative Humidity, Vapor Pressure Deficit	2	
Container Production Greenhouse High Tunnel	Soil Moisture Electrical Conductivity Temperature Relative Humidity Vapor Pressure Deficit Irrigation Quantity	✓	nM50 Or EM50G	10HS	Large Sensing Volume	5	2
				GS1	Increased Durability		
				EC5	Smaller Sensing Area & Reduced Cost		
				GS3	Electrical Conductivity, Substrate Temp., Substrate Moisture	2	
			nC24	VP3	Air Temp., Relative Humidity, Vapor Pressure Deficit	2	1
				Flow Meter	Irrigation Quantity	1	

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Buying a Decagon system

The control sensor networks that we have described above have been commercialized by Decagon Devices, Inc. (www.decagon.com). However, Decagon ONLY sells equipment through a network of distributors and consultants, since they are an equipment supplier, and do not have the expertise to handle installation and support of a wide range of crops and production situations. Hence, they rely on consultants to provide that information directly to growers, as experts in those specific crops or agricultural sectors. There are a number of benefits in this business model for you as a grower, as discussed below.

Benefits of a consultant network

A consultant should be able to advise and customize a system for your operation, taking into account your needs, current and future growth, and how you plan on using the information from a sensor network. Since consultants should be familiar with the many different types of sensors and nodes combinations, they can help you find the most cost effective and useful configuration for your particular situation. Consultants will also show you how to use the hardware and software, which can reduce time and energy involved in getting the system up and running. Consultants typically also offer installation services, which can get you up and running within a few hours, since they are familiar with, not only what sensors to use, but where to best place them (see the learning modules on variability). Having set up many networks, they can also troubleshoot problems more effectively. Lastly, a consultant can demonstrate value to the grower by advanced sensor data analysis packages, to illustrate where practices are already efficient, but also highlight areas for improvement. Good consultants will integrate their experiences from other operations and add value to your operation, by passing that knowledge on to you.

What to look for in a consultant

There are a number of different factors to consider when contracting with a distributor/consultant. First and foremost, it is important to hire someone who has a demonstrated knowledge of Decagon equipment, and who you feel confident can design a system that fits your needs. Typically a consultant should provide you with examples of prior installations and how those installations have provided a reasonable return on investment. Purchasing the correct equipment is essential for the sensor network to function as expected. In addition, make sure that they are able to provide you with the level of installation of equipment and training on the software (and hardware as necessary) to be able to effectively use the sensor network. Training should be a part of any sensor installation package. If required, a consultant should also be able to provide additional services such as maintenance, monitoring and advanced consultant services. These additional services would vary depending on the size and type of operation you own and the level of additional expertise you require.

Determining your payback period

The value you derive from a sensor network is determined by the size and complexity of your operation, the number and type of nodes and sensors you purchase, and how you use the information from the network to make decisions about your operation.

In order to help you evaluate the benefit of a sensor network for your operation, we have created an excel spreadsheet that will be discussed in the return on investment learning module. There you can enter information about your operation, and the type of sensor network that you would be interested in etc. Based on the information you provide, the spreadsheet will help you make an informed decision about the benefits of a sensor network at your operation.

Conclusions

As we have seen, sensor networks can be a useful tool to help you produce higher quality plants. Just like any tool, they will take some time to fully evaluate and the information should be used for changing management practices, in order to achieve the maximum benefit. The benefits that are seen from sensor networks are dependent on a number of factors such as the size of the operation, the type of plants grown, and the type and size of the sensor system that is purchased. In general, sensors have been shown to reduce a number of costs including labor, water and fertilizer. In addition, sensors are able to increase profitability by shortening production time, and reducing disease losses, and increasing quality. They are able to provide important information, in real-time to help guide fertilizer applications through EC monitoring, and regulate growth through deficit irrigation.

Since this technology is relatively new, additional benefits are likely to be discovered through further research, and technology advances. Although there are no guarantees that a sensor system will increase your profitability, the information in the next module will help inform your decision, to give you the most information possible

Additional Resources:

Alem, P., P. A. Thomas, and M.W. van Iersel. 2014. Use of controlled water deficit to regulate poinsettia stem elongation. Achievable heights. *HortScience* (in press)

Belayneh, B. E., J. D. Lea-Cox and E. Lichtenberg (2013). "Costs and Benefits of Implementing Sensor-controlled Irrigation in a Commercial Pot-in-Pot Container Nursery." HortTechnology 23(6): 760-769.

Lichtenberg, E., J. Majsztrik and M. Saavoss (2013). "Profitability of Sensor-based Irrigation in Greenhouse and Nursery Crops." HortTechnology 23(6): 770-774.