A. PROJECT INFORMATION

Adjustable-Rate Fertigation for Site-Specific Management to Improve Fertilizer Use Efficiency

CDFA-FREP #10-0004-SA Final Report, July 2011 - June 2013

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B. OBJECTIVES

In this project, we developed simple technology to allow adjustable-rate fertilizer injection, which was integrated with a wireless control network. Our overall goal was to improve fertilizer use efficiency through site-specific fertigation. The objectives of this work were:

1. Develop a simple fertilizer injection system to give adjustable-rate fertigation.
2. Integrate the injector with the wireless irrigation control system to give automated, adjustable-rate fertigation for nurseries.

C. ABSTRACT

Site-specific fertigation can limit fertilizer waste and loss to the environment, but cannot be easily implemented when there are many small hydrozones each demanding a unique rate of fertilizer application. With a simple and inexpensive fertilizer injection system, a separate injector could be installed at each zone to provide a unique fertilizer delivery rate, even when those zones are in simultaneous operation. Integration with a wireless control network would allow automated adjustment of the fertilizer delivery rate for each hydrozone. A variable-rate injector was developed using a simple venturi injector, solenoid valve, electrical conductivity (EC) sensor, and small computer board (controller). EC was related to fertilizer concentration expressed as parts-per-million nitrogen. Fertilizer injection rate was controlled by pulsing a solenoid valve connected to the suction line of the venturi injector. The rate was adjusted by changing the valve duty cycle (percentage of time that the valve was open). Increasing the duty cycle allowed more fertilizer stock solution into the injector. Decreasing the duty cycle allowed less fertilizer into the injector. For a 2000 ppm N stock solution, it was shown that the duty cycle could be adjusted from 0 to 100% to deliver an applied fertilizer concentration of 0 to 200 ppm N. The controller was programmed to monitor EC and automatically increase or decrease

the valve duty cycle in order to achieve a target fertilizer concentration. The adjustable-rate system correctly delivered 0, 50, 100, 150, and 200 ppm N in field tests. A mobile injector station was assembled and integrated with a new wireless sensor and control network in order to test adjustable-rate fertigation in container nurseries. At each of several beds, fertilizer was injected at a different rate. The fertilizer concentrations matched that specified by the user, indicating that the system did a good job of adjusting the duty cycle to meet the target rate, and the irrigation and fertilizer injection durations were correct. Furthermore, the wireless network performed well and exhibited good range. In coordination with another project, a separate wireless sensor and control network was installed at two container nurseries to control irrigation to individual beds of plants based on real-time soil moisture measurements. Water use was reduced by 35% with automated irrigation in one nursery, but increased water use in a second nursery. A modified control methodology, such as mid-season threshold adjustments by the grower, could have reduced water use in the second nursery. Measurements of leachate showed that automated control reduced runoff containing fertilizer by 23% or more compared to grower controlled beds in nursery 1 and 60% or more in nursery 2. Overall, wireless sensor and control networks coupled with adjustable-rate injection systems provide valuable tools for growers to implement site-specific techniques that improve nursery management and optimize water and fertilizer use.

D. INTRODUCTION

Uniform application of dissolved fertilizer within large irrigation zones of commercial nurseries will over-fertilize some plants since the fertilizer requirement is based on those with the greatest need. Similar problems exist with many other specialty crops. By decreasing the size of the irrigation/fertigation zones and separating plants based on water and nutrient needs, site-specific fertigation can limit fertilizer waste and loss to the environment. However, using conventional fixed-rate injection may not be possible due to the time required to fertigate a large number of zones independently. It is possible to deliver different fertilizer rates to simultaneously-operating zones, but it is complicated (Coates et al., 2012). Zones can be fertigated at different rates by using different durations of fixed-rate fertilizer injection for each zone, but more effective control of fertilizer application could be achieved by automatic adjustment of the injection rate for each zone. The ability to automatically vary the rate of injection will provide greater flexibility to deliver fertilizer to multiple zones. With a simple and inexpensive injection system, a separate injector could be installed at each zone to provide a unique fertilizer delivery rate. Installation and management of injectors at small, site-specific zones would be simplified by using wireless sensing and control technology.

E. WORK DESCRIPTION

Objective 1. Develop a simple fertilizer injection system to give adjustable-rate fertigation.

Task 1.1. Review existing injection technologies. (year 1)

Our first task under objective 1 was to review the existing injection technologies and select a simple system that can be used off-the-shelf, or with minor modification, to provide injection-rate adjustment by electronic control. In industry today, the four main types of fertigation systems are centrifugal pumps, positive displacement pumps, pressure differential methods, and methods based on the venturi principle (Haman, 1998). Each method has advantages and disadvantages.

The main advantage of pumping systems is that they can accurately inject fertilizer into the system and require no feedback control. They are easy to install and have a high chemical resistance. Disadvantages are that pumps have moving parts and are expensive to buy and maintain. They also require an external power source to operate. Our system needs to be low power for easy installation and mobile use.

Pressure differential methods rely on water pressure to push or pull fertilizer into the irrigation line. Pressure differential injection has the advantage of being relatively inexpensive, but has the disadvantage that it often requires the injector to be located near the irrigation pump so that fertilizer can be injected on the suction side of the pump, which is not feasible for a site-specific system or system with a municipal water supply. Other methods use pressure from the irrigation line to push fertilizer into the line downstream. The systems for this typically require tanks that are frequently refilled or do not provide a constant rate of injection.

Venturi-based systems are controlled by the water that flows through them. The main advantages are that they require no electrical power and are relatively inexpensive and durable, since most are made from noncorrosive plastic. Disadvantages are that venturis cannot consistently inject the same amount of fertilizer over time because they require a pressure differential to operate and pressure changes occur frequently in real installations (Schwankl and Prichard, 2001).

This task was completed in December 2011.

Task 1.2. Develop simple variable-rate injector. (years 1-2)

We decided to use a venturi-based injector because they are relatively inexpensive, require no electrical power, and can easily have valves and metering devices installed. Venturi injection is based on a restriction in the cross-sectional area of a pipe, which increases the fluid velocity and decreases static pressure around the point of restriction. A suction line is connected to a port in the restriction area, which then allows injection of concentrated fertilizer stock solution. Typically the venturi is put in a by-pass of the main-line in order to create an adequate pressure differential to achieve negative pressure on the suction line (Figure 1). A flow regulator or valve may be used to restrict flow. In our variable-rate fertigation system, an inline electrical conductivity (EC) sensor on the downstream side of the injector sent conductivity information back to a computer control board. The controller drove a solenoid valve at a fixed frequency and changed the duty cycle (percent of time valve is open) to adjust the average downstream fertilizer concentration to the desired value.

Our first prototype (Figure 2) consisted of a 384 gal/hour venturi injector (Model 384, Mazzei Injector Company, Bakersfield, California, USA). It was plumbed in parallel with a main-line flow control valve that could be adjusted to achieve an adequate pressure differential across the venturi. A two-way, normally closed solenoid valve with an orifice diameter of 3/32” (Alcon Model 02BZ072B1-4CCF, Xylem Alcon, Santa Ana, California, USA) was on the suction line of the venturi. The inline EC sensor (Model CDH-722, Omega Engineering, Stamford, Connecticut, USA) had a probe connected to the outlet of the main-line and injector lines, and a display to show the measured EC.

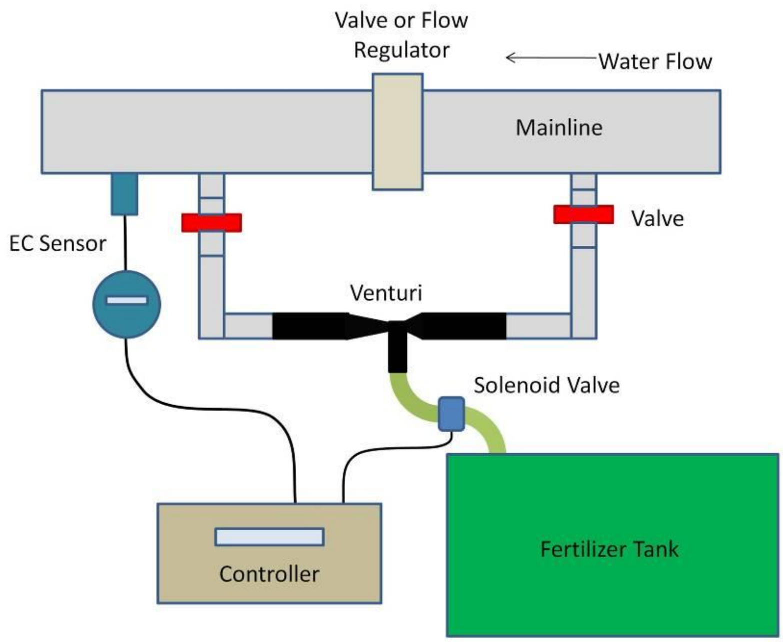

Figure 1. Diagram of the variable-rate injector using venturi, valve, and electrical conductivity sensor.

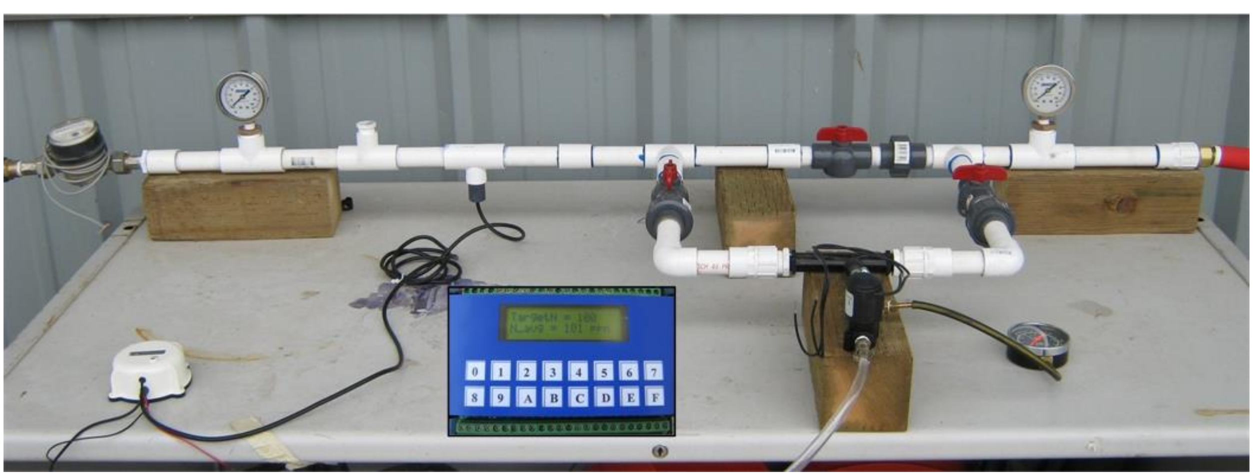

Figure 2. Prototype variable-rate fertigation system, showing the venturi injector and solenoid valve on the fertilizer tank suction line, pressure gauges, inline EC sensor, and controller (inset).

Automatic adjustment of the suction valve duty cycle was implemented with an embedded controller (TD40, Tern Inc., Davis, California, USA). The controller was a small computer board that was programmed to measure the EC sensor signal and output a pulse signal with variable duty cycle. The keypad prompted the user to enter the target fertilizer rate as parts-per-million nitrogen. The user then pressed a button to begin background EC measurement and injection. The controller first monitored the background EC of water through the main-line. The user then partially or fully closed the main-line and opened the valves to the injector lines. The controller estimated the starting duty cycle and started to pulse the suction line valve open and closed. During operation, the EC was continually monitored and a running average of the EC signal was calculated over several pulse cycles of the suction line valve. EC was converted to nitrogen concentration and compared with the target concentration. The valve duty cycle was automatically decreased if the measured concentration was too high and increased if the measured concentration was too low.

The final design included solenoid valves to control the flow of water through the main-line and venturi injector (Figure 3). A wireless node passed irrigation and fertigation control parameters to the controller. A manual gate valve provided the ability to adjust the pressure drop across the venturi. The completed injector system was assembled and mounted on a wheeled cart with a fertilizer tank (Figure 4).

This task was completed in December 2012.

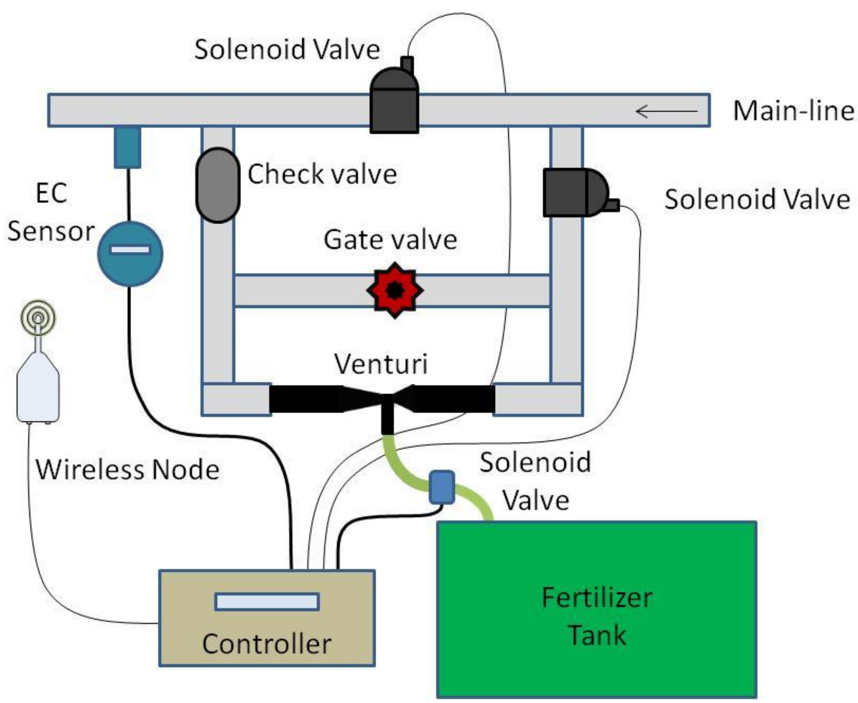

Figure 3. Diagram of the variable-rate injector using venturi, solenoid valves, electrical conductivity sensor, injection controller, and wireless node.

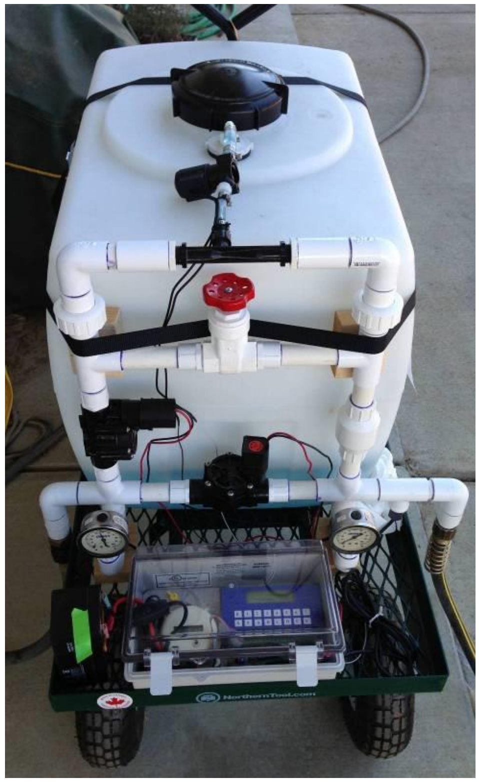

Figure 4. Mobile fertilizer injector with tank, valves, EC sensor, and controller.

Objective 2. Integrate the injector with the wireless irrigation control system to give automated, adjustable-rate fertigation for nurseries.

Task 2.1. Integrate variable-rate injector with wireless control system. (years 1-2)

In our previous FREP project we developed an experimental wireless network for site-specific irrigation and fertigation (Coates and Delwiche, 2009). Wireless nodes eliminate the need for wired valves, thus allowing simpler installation and management of small hydrozones. The network used mesh networking to extend the effective communication range without high power radios. Solar energy was collected with a miniature panel to operate each node without yearly battery replacement. Nodes controlled latching solenoid valves and sent sensor data back to a central field controller. Electrical conductivity (EC) sensors were used to monitor fertilizer concentration and location within the lines. We developed strategies that can be implemented for site-specific fertigation in a variety of applications (Delwiche et al., 2009; Coates et al., 2012). To control fertigation at individual hydrozones in a nursery, an injection controller would be connected to a wireless node at the inlet of each zone (Figure 5). This would allow individual control of fertigation levels in simultaneously-operating hydrozones.

In coordination with work on another CDFA-funded project (Delwiche, 2012), we adopted a commercial version of the wireless network (eKo, MEMSIC Inc., Andover, Massachusetts, USA) that used the same technology as our previous work. The eKo system was originally designed for sensors only, so we added valve control capability (Coates et al., 2013) for automated control in container nurseries. Automated control in container nurseries was tested with this system.

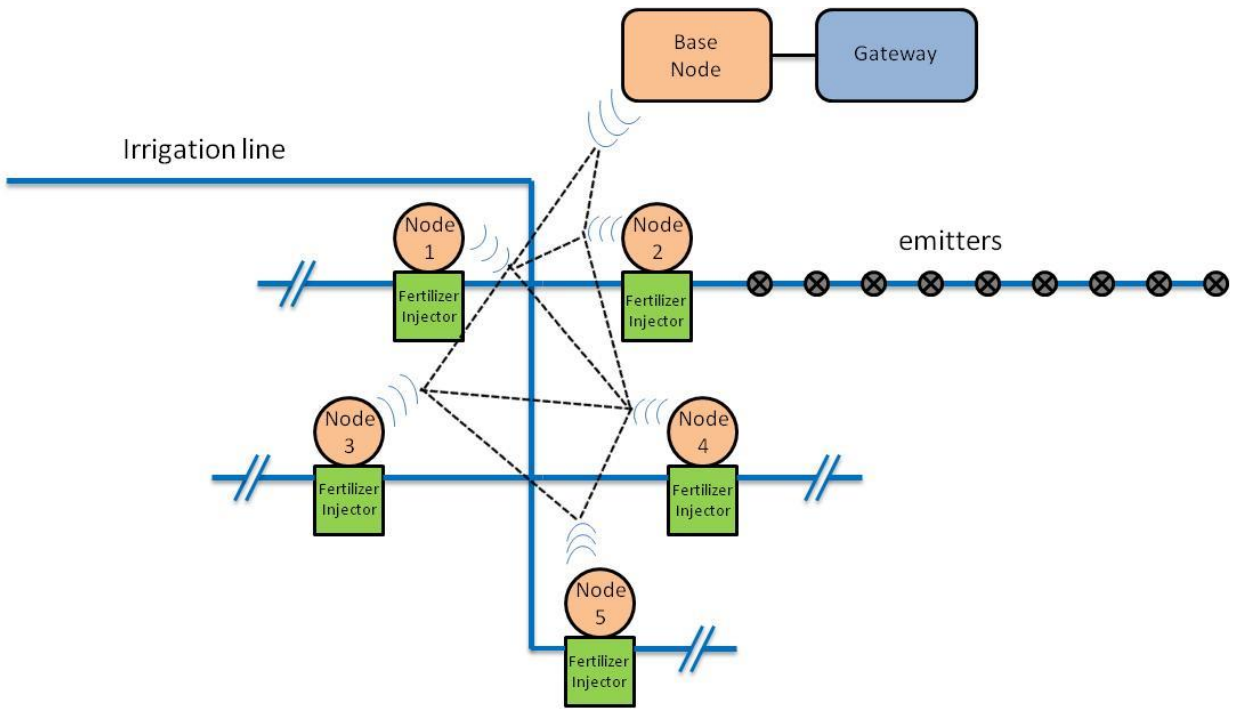

Figure 5. Wireless network for controlled fertigation.

We also began development of a new wireless sensor network platform that is similar to eKo and other commercially-available systems, but will cost substantially less and provide greater flexibility for customization. This system was based on 900 MHz radios with mesh-networking software (XBee Pro with DigiMesh, Digi International Inc., Minnetonka, Minnesota, USA). The DigiMesh software also used a mesh-network topology, meaning radios can relay messages between each other. The radios were tested and found to have an excellent range – up to 2 miles under ideal conditions. The goal was to demonstrate the effectiveness of this new technology and promote its commercialization. One of these radios was integrated with the fertilizer injection system to provide wireless control capability (Figure 6).

The radio was interfaced with the injection controller through a communication port. The gateway was programmed to send fertigation parameters through the base radio to an injector-connected wireless node. Fertigation commands could be started through a web page and could be accessed by mobile devices (Figure 7). These parameters were passed from the node to the controller through the communication port. Once parameters had been received, the controller began a fertilizer injection sequence (Task 2.2).

This task was completed in June 2013.

Figure 6. Controller display indicating that a wireless command was received.

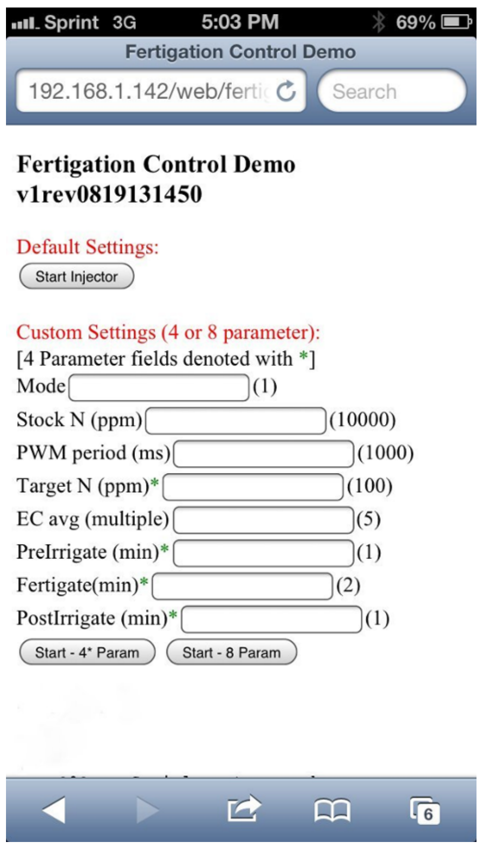

Figure 7. Web page on a mobile device to start fertigation.

Task 2.2. Test site-specific fertigation with variable-rate injector. (year 2)

In coordination with our other CDFA-funded project, wireless networks were installed at two commercial nurseries, each with 9 beds of 60 to 120 plants using drip irrigation with fan-spray stakes (Figure 8). Valves and water meters were installed to control and measure the water applied in each bed. We conducted tests on automated irrigation control using soil moisture sensors for different control scenarios. Water consumption, plant growth, plant health, and leachate (water and fertilizer) runoff were monitored over several months to compare automated, variable-rate control with grower control. The goal was to reduce overall water consumption and fertilizer runoff by applying water based on plant demand. The results were reported to the CDFA (Delwiche, 2012).

Figure 8. Wireless nodes installed in a container nursery.

For fertigation tests, the fertilizer injector was programmed to complete a single injection sequence based on the parameters in Table 1. Some values (i.e., T_PWM, Intgr_EC) were technical in nature and could be set to defaults. Once parameters were received by the controller, a fertilizer injection sequence was begun. The injection sequence is shown in Table 2. First, water was applied for 20 seconds and measurement of the background EC was made. Then water was applied for the 'Prewater' duration. Fertilizer injection began with a suction valve duty cycle that was estimated based on the target fertilizer rate. The duty cycle was then automatically adjusted by the controller in response to feedback from the EC meter, as described for Task 1.2. The target fertilizer rate was typically reached in about 30 seconds and then held stable for the duration of injection. Last, water was applied to flush the lines for the 'Postwater' duration.

The mobile fertilizer injection station was used to inject fertilizer in a commercial nursery. Quick connect fittings (Figure 9) were used on the grower lines to allow the injector to be connected or disconnected easily from each point of injection. The injector was connected to a bed of plants in the nursery. A mobile phone was used to access the fertigation control web page and start injection of 20-20-20 fertilizer for 2 minutes with a target nitrogen rate of 100 ppm. Irrigation and fertigation timing were monitored to ensure correct operation and a water sample was collected from the microsprayers during fertilizer injection to verify the fertilizer concentration (calculated based on EC measurement with a separate meter). The mobile injector was moved to several different beds of plants and injection was started using different fertilizer injection rates. Operating time and injection rate at each location were verified.

Table 1. Parameters entered by user or sent by wireless radio to fertigation controller.

Parameter	Description	Units	Default value
T_PWM	Suction valve pulse period	millisecond	1000
Intgr_EC	T_PWM periods for average EC	(none)	5
Stock_N	Stock solution fertilizer concentration	ppm nitrogen	2000
Target_N	Target fertilizer concentration	ppm nitrogen	100
Prewater	Irrigation duration before injection	minute	1
Fertigation	Fertilizer injection duration	minute	2
Postwater	Irrigation duration after injection	minute	1

Table 2. Sequence of injection operations.

Order	Operation	Duration
1	Measure background EC	20 sec
2	Irrigate before start of fertilizer injection	'Prewater' min
3	Inject fertilizer – adjust duty cycle to reach Target_N	'Fertigation' min
4	Irrigate after end of fertilizer injection	'Postwater' min

This task was completed in June 2013.

Figure 9. Quick connect adapters allow a mobile injector to be connected and disconnected from a hydrozone.

F. DATA AND RESULTS

The in-line EC sensor has a working range from 0 to 10 mS/cm, corresponding to 0 to 2000 ppm nitrogen (N) in distilled water. We tapped into the circuitry of the EC sensor to gain access to an analog signal, which was measured by the controller. The EC sensor was calibrated with standards mixed from 20-20-20 fertilizer in distilled water and tap water, from 0 to about 2000 ppm N. Tap water at UC Davis has a background EC of about 0.53 mS/cm, which shifted the calibration curve up by an equivalent amount. EC measurements (mS/cm) were converted to nitrogen concentration, [N] (ppm), using the calibration equation slope and the background EC (mS/cm) measured before each injection by the equation:

$$[N] = (EC - \text{Background EC})/0.0041.$$

Tests were completed using the first prototype with a 2000 ppm N stock solution in the fertilizer tank to examine the potential of the system to control the downstream fertilizer concentration. The first tests were done by pulsing the valve at a fixed duty cycle with a function generator, driver circuit, and 12 V power supply. Duty cycles of 0, 13, 27, 39, 50, 61, 72, 86, and 100% were tested at a drive frequency of 1 Hz. (A duty cycle of 0% means the valve is always off, and 100% means the valve is always on.) Average EC was calculated during injection using the inline sensor measurements and was compared with the EC of a water sample collected from the downstream emitters, measured using a bench-top EC meter. The injector ratio was calculated to be about 1:10. Therefore, with a 2000 ppm N stock solution, the fertilizer solution was expected to be 200 ppm N at 100% duty cycle and a fraction of this at lower duty cycles (e.g., 100 ppm at 50% duty cycle).

Figure 10 shows the average nitrogen concentration measured with the inline sensor, expected nitrogen concentration based on the duty cycle, and nitrogen concentration of the sample collected at the emitter for duty cycles from 0% to 100%. Both the inline EC and sample EC measurements resulted in higher than expected nitrogen concentrations, although the trend showed that fertilizer concentration was proportional to the duty cycle of the suction valve. We expected that automatic control of the duty cycle based on real-time EC measurements would improve the accuracy of injection.

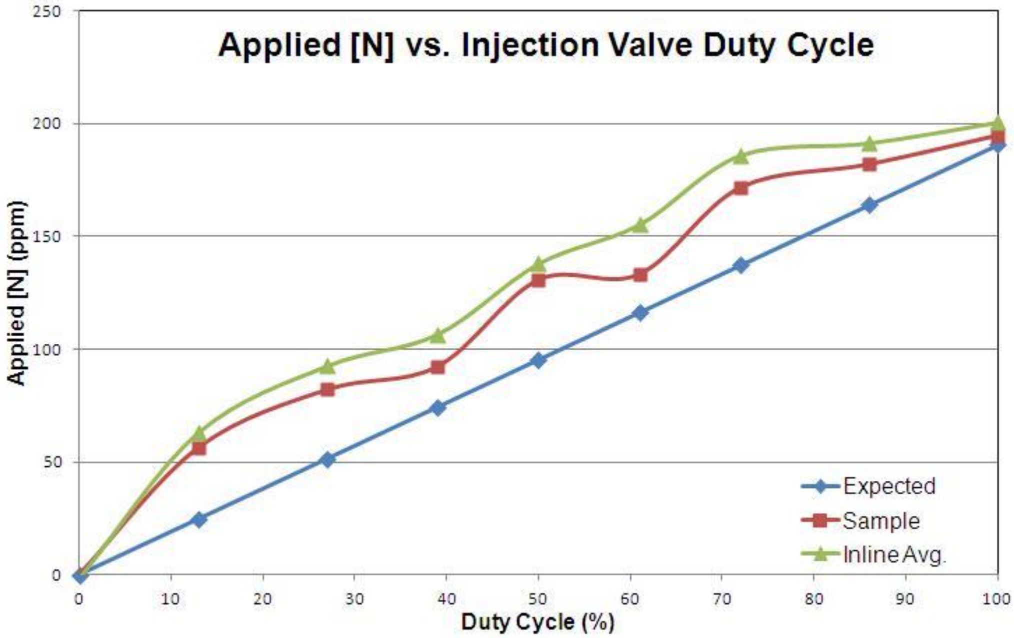

Figure 10. Expected and measured nitrogen concentrations of fertilizer solutions delivered by adjustment of duty cycle to venturi suction valve.

Figure 11 shows the signal from the EC sensor and the pulse signal controlling the suction valve for injector control using real-time feedback. Figure 12 shows the controller displaying the target nitrogen injection concentration (100 ppm) and the average measured concentration during operation. In that particular test, the average concentration varied from 99 to 105 ppm. If the injected fertilizer concentration changed due to pressure changes across the venturi injector, poor stock mixing, or other conditions, the controller automatically adjusted the duty cycle to compensate. Figure 13 shows the target nitrogen concentration and the nitrogen concentration of the sample collected at the emitter for several target concentrations between 0 and 200 ppm N. The controller did well at applying fertilizer at the target rate.

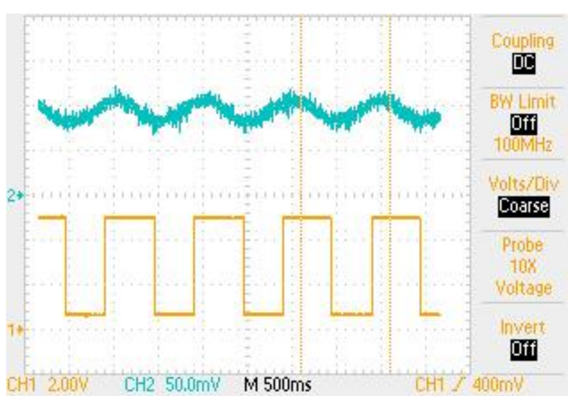

Figure 11. Oscilloscope waveforms for suction valve pulsed at approximately 50% duty cycle (bottom square wave) to achieve target rate of 100 ppm N and EC meter voltage (top sine wave) showing the fluctuations in fertilizer concentration during injection.

Figure 12. Controller displaying the target nitrogen concentration and the average measured concentration during fertilizer injection.

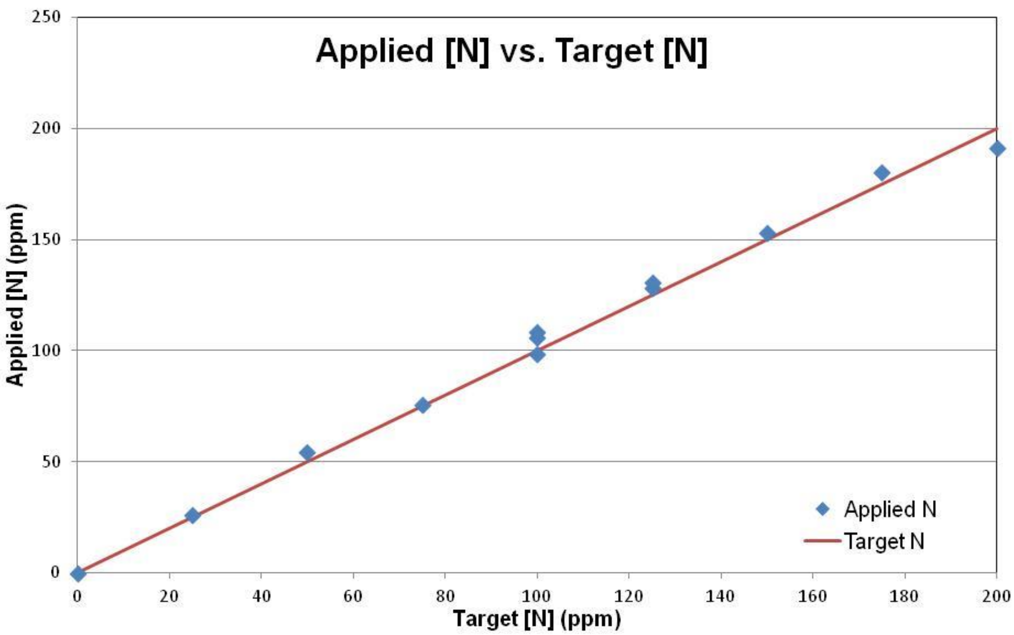

Figure 13. Target and measured nitrogen concentrations of fertilizer solutions delivered by automatic control of duty cycle to venturi suction valve.

A wireless sensor and control network was tested at two container nurseries to control irrigation to individual beds of plants based on real-time soil moisture measurements. Water use was reduced by 35% with automated irrigation in one nursery, but increased water use in a second nursery. A modified control methodology, such as mid-season threshold adjustments by the grower, could have reduced water use in the second nursery. Measurements of leachate showed that automated control reduced runoff containing fertilizer by 23% or more compared to grower controlled beds in nursery 1 and 60% or more in nursery 2. This was likely due to more frequent irrigation for shorter durations compared to grower control.

The mobile injector system was integrated with a new wireless network in order to test adjustable-rate fertigation in container nurseries (Figure 14). At each of several beds, fertilizer was injected at a different rate. Fertilizer concentrations for each test are shown in Table 3. The gate valve was opened to allow greater flow and the stock concentration was increased to 10000 ppm N in this test, so the suction duty cycle for each target rate did not match those in previous tests. The fertilizer concentrations matched that specified by the user, indicating that the system did a good job of adjusting the duty cycle to meet the target rate, and the irrigation and fertilizer injection durations were correct. Furthermore, the wireless network performed well and exhibited good range.

Figure 14. Fertilizer injector connected to a bed of nursery plants.

Table 3. Target and measured N concentration, and suction valve duty cycle for fertilizer applied at 4 beds in a container nursery.

Nursery bed	Target N (ppm)	Measured N (ppm)	Suction valve duty cycle (%)
1	100	103	42
2	50	51	14
1	150	151	70
3	75	77	29
1	125	127	56

G. DISCUSSION AND CONCLUSIONS

Simple variable-rate injection using a venturi injector, solenoid valve, EC sensor, and embedded controller was effective. The controller was able to control the rate of fertilizer injection using a pulse-width-modulated valve on the venturi suction line. The applied fertilizer concentration remained very close to the target rate. This was the result of using EC for feedback control. Feedback control provided both advantages and disadvantages. One advantage was that even if a user added extra fertilizer or water to the tank, the controller could adjust the duty cycle to compensate, so long as it did not reach 100% duty cycle (i.e., fertilizer tank solution too dilute to reach target rate) or become too small (i.e., fertilizer solution too concentrated to accurately control the rate of injection). This was demonstrated in tests during operation in the nursery. A related advantage of feedback control was that the user did not have to accurately mix the stock solution. One disadvantage of using feedback control was that the injector would not be able to control the rate of some chemicals (e.g., pesticide) that a grower may wish to inject since these do not product a sufficient change in EC. For these chemicals, the stock solution must be carefully mixed and the injector could be set to operate in a fixed-duty-cycle mode.

Separate, fixed-location injectors located at each hydrozone would allow a different rate of fertilizer injection to each zone, even while operating simultaneously. This was tested with a mobile injector, moved between different locations. Alternatively, a single injector that serves multiple hydrozones, each with a control valve, could automatically adjust the injection rate for each zone. Integration with wireless communication provides a simple way to deploy a system for automated control of fertilizer delivery.

During tests in commercial nurseries, a wireless network was able to monitor crop water levels and reduce water use and runoff of fertilizer. The system also helped detect faults, such as improper flow rates. A few times, growers did not fully close manual irrigation valves. The continuous use of water was evident in data from the sensor network and the problem was addressed earlier than it might have been otherwise.

In conclusion, wireless sensor and control networks coupled with adjustable-rate injection systems provide valuable tools for growers to implement site-specific management techniques that improve nursery management and optimize water and fertilizer use.

H. PROJECT IMPACTS

By providing a means to automatically control the amount of fertilizer delivered to different fertigation zones, this technology reduces waste and promotes the environmentally safe and agronomically sound use of fertilizing materials. Based on discussion with growers, the system would be most attractive for managing large blocks of plants with contrasting water and fertilizer needs (e.g., one block that requires constantly moist soil versus one that must dry out between irrigation events or zones that require different amounts of fertilizer).

There are two primary barriers to grower adoption of this system: installation and cost. Wireless technology eliminates the need for long wires to site-specific hydrozones, but plumbing must still be modified. While a new nursery could design irrigation plumbing to best accommodate variable-rate control, most nurseries are already established and adding new hydrozones may be difficult. System adoption by growers also depends on the type of irrigation system design being used. For example, for individual beds of 100 micro-irrigated plants, placing an injector at each bed would likely be cost-prohibitive at this time. The cart, tank, valves and plumbing, controller and electronics, and EC meter cost about $1300, excluding assembly labor. A large portion of this was the controller ($480), tank ($300), and optional cart ($90). The system could be made less expensively by using lower cost components and in greater quantity. Larger beds or a group of beds would make automated sensing and control more economically feasible due to savings in water, fertilizer, and labor. The possibility of environmental regulations that impose strict runoff monitoring or abatement practices could also be addressed through more frequent, shorter duration irrigation control and controlled fertilizer injection with an automated system.

I. OUTREACH ACTIVITIES SUMMARY

The wireless network was deployed in two container nurseries for testing of the wireless network, sensor data collection, and irrigation control. We established a good working relationship with both growers, who are interested in the application of wireless networks for their own business and that of colleagues in the nursery industry. We met with the growers at the commercial nurseries on many occasions to discuss research results. The variable-rate injector was integrated with a new wireless network technology and tested at a commercial nursery. The grower was very interested in the fertilizer injection system and possible applications of the mobile and fixed location configurations. This work was presented at the FREP annual conference in October 2012 and will be submitted for publication in a peer-reviewed journal.

J. FACTSHEET/DATABASE TEMPLATE

Adjustable-Rate Fertigation for Site-Specific Management to Improve Fertilizer Use Efficiency

CDFA-FREP #10-0004-SA

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July 2011 - June 2013

Locations

- University of California, Davis
- Village Nurseries, Sacramento
- Four Winds Growers, Winters

Counties

- Sacramento, Solano, Yolo

Highlights

- Developed a simple variable-rate injector for site-specific fertilizer management and integrated a wireless network for remote access and automated control.
- Improved water and fertilizer use efficiency by using a wireless network of sensors to apply water only when needed.
- One or more site-specific injectors could be installed in fixed locations to deliver fertilizer to multiple hydrozones or be mounted on a mobile platform to temporarily connect to hydrozones for special injection needs.

Introduction

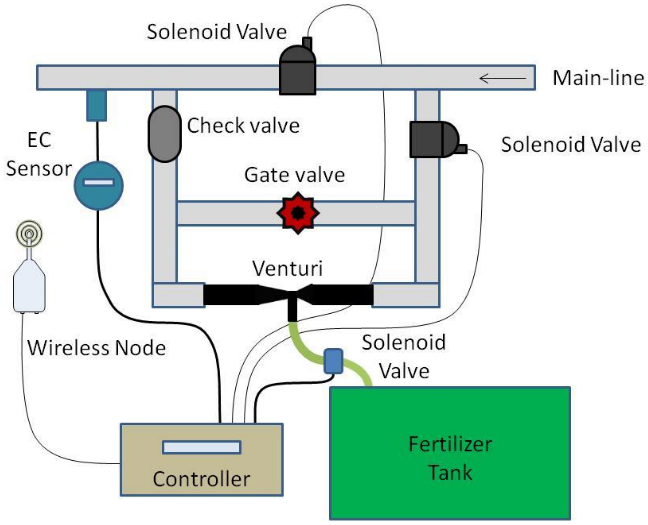
Uniform application of dissolved fertilizer within large irrigation zones of commercial nurseries will over-fertilize some plants since the fertilizer requirement is based on those with the greatest need. Similar problems exist with many other specialty crops. Site-specific fertigation can limit fertilizer waste and loss to the environment, but cannot be easily implemented when there are many small hydrozones each demanding a unique rate of fertilizer application. With a simple and inexpensive fertilizer injection system, a separate injector could be installed at each zone to provide a unique fertilizer delivery rate, even when those zones are in simultaneous operation. Integration with a wireless control network would allow automated adjustment of the fertilizer delivery rate for each hydrozone.

Methods/Management

A variable-rate injector was developed using a simple venturi injector, solenoid valve, electrical conductivity (EC) sensor, and small computer board (controller). EC was related to fertilizer concentration expressed as parts-per-million nitrogen. Fertilizer injection rate was controlled by pulsing a solenoid valve connected to the suction line of the venturi injector. The rate was adjusted by changing the valve duty cycle (percentage of time that the valve was open). Increasing the duty cycle allowed more fertilizer stock solution into the injector. Decreasing the duty cycle allowed less fertilizer into the injector. For a 2000 ppm N stock solution, it was shown that the duty cycle could be adjusted from 0 to 100% to deliver an applied fertilizer concentration of 0 to 200 ppm N. The controller was programmed to monitor EC and automatically increase or decrease the valve duty cycle in order to achieve a target fertilizer concentration. The adjustable-rate system correctly delivered 0, 50, 100, 150, and 200 ppm N in field tests. A mobile injector station was assembled and integrated with a new wireless sensor and control network in order to test adjustable-rate fertigation in container nurseries.

Findings

At each of several beds, fertilizer was injected at a different rate. The fertilizer concentrations matched that specified by the user, indicating that the system did a good job of adjusting the duty cycle to meet the target rate, and the irrigation and fertilizer injection durations were correct. Furthermore, the wireless network performed well and exhibited good range. In coordination with another project, a separate wireless sensor and control network was installed at two container nurseries to control irrigation to individual beds of plants based on real-time soil moisture measurements. Water use was reduced by 35% with automated irrigation in one nursery, but increased water use in a second nursery. A modified control methodology, such as mid-season threshold adjustments by the grower, could have reduced water use in the second nursery. Measurements of leachate showed that automated control reduced fertilizer containing runoff by 23% or more compared to grower controlled beds in nursery 1 and 60% or more in nursery 2. Overall, wireless sensor and control networks coupled with adjustable-rate injection systems provide valuable tools for growers to implement site-specific techniques that improve nursery management and optimize water and fertilizer use.



K. COPY OF PRODUCT

The results of this project will be submitted for publication in a peer-reviewed journal. A copy of all related publications will be provided to FREP.

LITERATURE CITED

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