# Site Specific Fertilizer Application in Orchards, Nurseries, and Landscapes

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## Objectives

Variations in plant nutrient demand and environmental regulations provide significant incentive for development of fertigation systems which allow control of water and chemicals at a resolution smaller than the entire field or nursery block. In previous work we were able to control the amount of water from individual microsprinklers in an orchard, but operational strategies to apply a prescribed amount of fertilizer at a specific location are considerably more complicated. Ease of installation and simplicity of operation point to elimination of wires from the system. Therefore, our objectives in this research project are:

(1) Develop general operating strategies for spatially controllable fertigation to allow application of prescribed amounts of fertilizer at specific locations.

(2) Design a wireless valve controller network to simplify the implementation of precision fertigation.

## Abstract

Variations in plant water and nutrient demand and environmental regulations to protect water quality provide significant justification for development of site-specific irrigation and fertigation systems. But to be accepted by growers, a system must be easy to install and operate. Accurate fertilizer application to each zone in a spatially-variable system requires an intelligent approach to monitoring fertilizer concentration and flow through the system. We have developed wireless valve controllers that self-assemble into a mesh network. Mesh networking means that controllers pass messages to extend the effective communication range without using high power radios. Solar energy is collected with a miniature panel to operate each controller node without yearly battery replacement. Nodes open or close a latching valve to control water and fertilizer flow and send sensor data back to a central field controller. Valves are operated when commanded by the field controller or when initiated by a locally stored schedule. Transmission range using 900 MHz radios with dipole antennas varied from 32 m to 217 m depending on obstructions and antenna height. A node's average energy use was about 6.6 mA-h/day and the solar panel produced 52 to 81 mA-h in full sun and 6 to 10 mA-h in shade. Electrical conductivity probes are being tested to monitor fertilizer concentration and location within fertigation lines. We have tested a 2-pin probe in UAN-32 and 20-20-20 (NPK) fertilizer solutions with 0 to 2000 μS/cm conductivities. Soil moisture, pressure, temperature, and other environmental sensors will also be used for feedback control and detection of problems. Such a network of intelligent valve controllers will allow growers in orchards, vineyards, nurseries, greenhouses, and landscapes to develop management practices that improve water and fertilizer use efficiency.

## Introduction

Precision management of irrigation and fertigation in orchards, nurseries, and landscapes is compromised by traditional sprinkler and drip systems, which are designed for uniform water and nutrient delivery and ignore the reality that demand often varies across fields and between individual plants. To complicate matters, fertigation uniformity may be adversely affected by factors such as flow time through the pipes, fertilizer diffusion in the pipes, and emitter clogging. Orchards, nurseries, and landscapes each have unique problems related to water and fertilizer management.

Orchards are high value permanent crops, commonly irrigated and fertigated using drip or microsprinklers. Differences in soil type and topography can affect the rate of infiltration and runoff. Another problem with modern fertigation systems is that growers sometimes inject fertilizer for only a short portion of the irrigation cycle (i.e., 1-2 hr). Recent research has shown that fertilizer may not reach the furthest emitters for as long as 45 minutes, indicating that some trees may not receive enough nutrient without adequate post-fertigation flushing. Emitter clogging and irrigation line damage further compound the problem of delivering water and fertilizer. Nurseries deal with continually changing inventory and must comply with environmental regulations limiting runoff and fertilizer leaching. Plants of differing size may be irrigated from the same source, so some will receive too much water and fertilizer while others will receive too little. In landscape operations, irrigation control also is important since a significant amount of California's available water is used for turf grass and ornamentals. Optimizing water delivery can conserve water and prevent fertilizer leaching and runoff.

We began considering these problems by developing a precision microsprinkler system for orchards under a previous FREP research project. Small valves located at each individual tree controlled the delivery of water and fertilizer. Recognizing that power and communication wires in the previously developed system would likely impede commercial adoption, we initiated development of a wireless network for site specific management. Wireless communication and solar power will eliminate the use of wires and will improve ease of installation and reduce problems associated with long-range wired communication and damage from animals and machinery. Larger valves will be used to control flow to multiple sprinklers or drip emitters (e.g., laterals) or smaller valves could control flow to individual plants or trees (e.g., each microsprinkler). Individual valve schedules will be different in order to match differing water and fertilizer requirements and can easily be changed to accommodate replants, disease, growth, or seasonal changes. Data from electrical conductivity, pressure, soil moisture, and flow sensors will allow intelligent water and fertilizer control, and automatic detection of line breaks and emitter clogging.

## Work Description & Results

### Fertigation Control (Objective 1)

*Task 1.1. Identify the factors involved in spatially variable control of fertigation.*

As valves open and close in a spatially variable irrigation system, water pressure and flow rate will change. In large fertigation systems we will also need to consider the time it takes for dissolved fertilizer to reach each emitter. When attempting to deliver fertilizer to individually controlled blocks or emitters at different rates or times, standard operating procedures may not apply. One possibility for providing spatially variable control is to analyze the hydraulics of the irrigation system and develop an equation to predict flow through each branch of the fertigation lines based on the location of emitters and whether they are on or off. This would require information about the pump, irrigation piping, emitter sizes, etc. Under ideal conditions, equations would be able to determine the location of the fertilizer head and tail at any given time after initiation of fertilizer injection. Since field conditions are never ideal and frequently change, sensors will be used to detect the fertilizer front instead of flow equations to predict the fertilizer front.

*Task 1.2. Adapt our microsprinkler system to implement the application algorithm.*

A positive-displacement fertilizer injector (Dosatron USA, Clearwater, Florida, USA) will be used to maintain the proper concentration of dissolved fertilizer as flow rate changes when valves are opened and closed. Electrical conductivity (EC) sensors in the irrigation line will detect a change in conductivity as the fertilizer head and tail pass through the irrigation system. Using fertilizer-specific calibrations, the actual concentration of fertilizer could also be determined. This information will be used to adjust fertigation timing at each control valve in real time.

A simple 2-pin EC probe (Omega Engineering, Stamford, Connecticut, USA) with threaded body was selected for ease of installation into an irrigation system (Figure 1). The probe has a 0 to 2000 µS/cm range. This will be suitable for nurseries and greenhouses with frequent fertigations using general fertilizer injected at about 100 to 450 ppm nitrogen. A greater range sensor will be needed for orchard and vineyard fertigations which typically use higher concentrations of nutrient (up to 10000 ppm nitrogen) and operate less frequently. The conductivities of fertilizer solutions were measured for Urea-Ammonium-Nitrate-32% (UAN-32) and a general NPK fertilizer (20-20-20) at known concentrations of nitrogen (Figure 2). Liquid UAN-32 alone has a nitrogen concentration of 421789 ppm (mg/L). Solutions of known concentration were made by dilution in distilled water, which has a conductivity of 0 µS/cm. Quantities of 20-20-20 were weighed on a laboratory scale and dissolved in distilled water to create solutions of known nitrogen concentration (ppm, mg/L) based on the fact that the fertilizer is 20% nitrogen by weight.

Figure 1. Electrical conductivity probe with threaded body for installation on fertigation line.

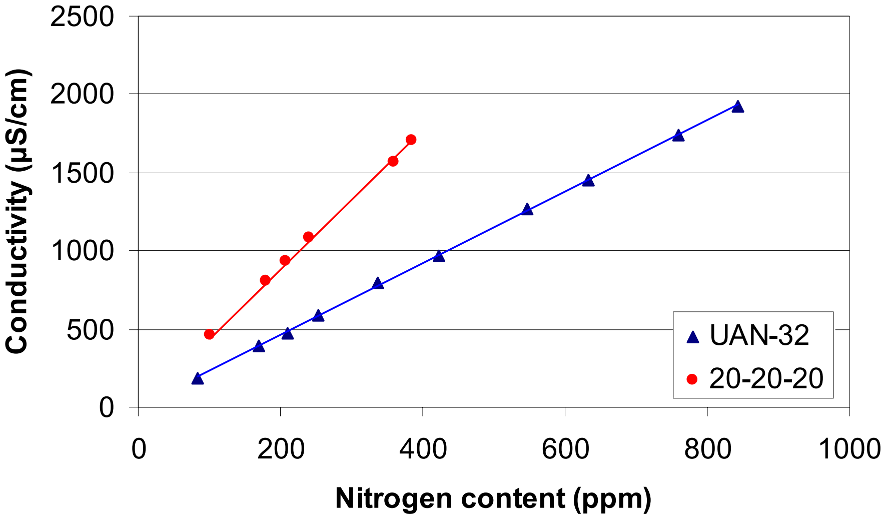


Figure 2. Electrical conductivity of fertilizer solutions with known nitrogen concentration.

## Wireless Design (Objective 2)

*Task 2.1. Design a valve controller capable of low-power, stand-alone operation, and wireless communication.*

*Task 2.2. Develop a communication network to link the valve controllers with a central field controller.*

Since this system is intended for application in orchards, greenhouses, landscapes, and nurseries, the wireless network (Figure 3) must be versatile enough to operate in many environments. Mesh networking will allow messages to pass from one node to any other node in the network by routing it through intermediary nodes. This technique allows increased network range without using high power transceivers. Another advantage is redundancy. A failed node will not disable the entire network since multiple routing paths exist between nodes. The operator will enter schedules on the field controller, and they will be distributed to the controller nodes in the network. Sensors that monitor parameters such as fertilizer electric conductivity (EC), pressure sensors, soil moisture, temperature, or humidity could be used for automatic triggering of irrigation and fertigation events. An optional personal computer could provide in-office control, but will not be required to operate the system.

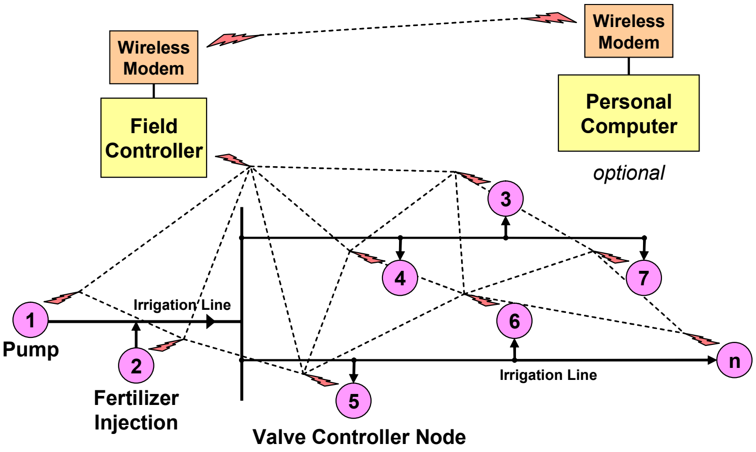
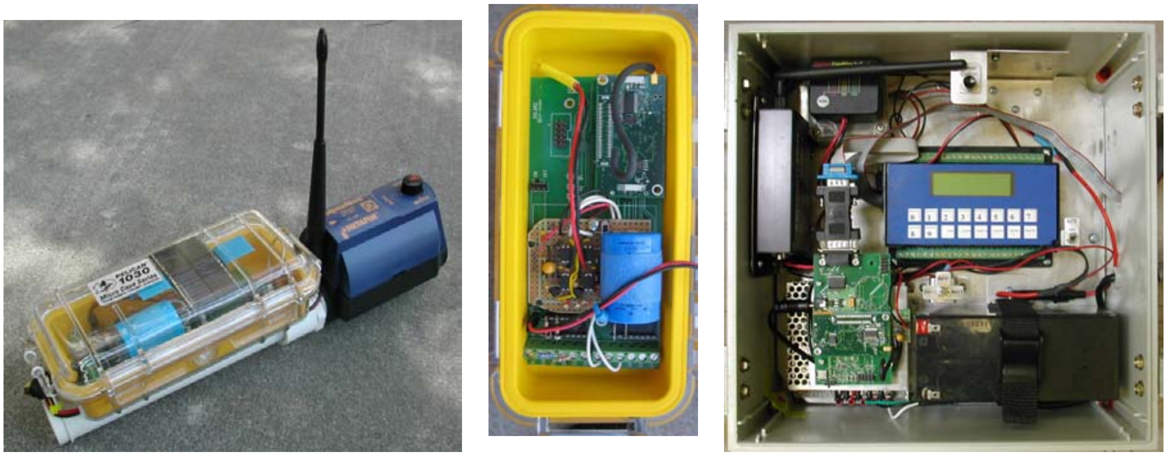


Figure 3. Layout of wireless valve network.

A 900 MHz low-power wireless module (Crossbow Technology, San Jose, California, USA) was adopted for our valve controller design (Figure 4a). These modules were selected because the mesh networking software is robust and the company is interested in developing products for agricultural monitoring and control, thus providing a good opportunity for collaboration and increased likelihood of future commercialization. The wireless module, along with a solar panel, battery, and valve switching circuitry, are connected to a prototype board from Crossbow Technology (Figure 4b). The components are housed in a clamshell-style polycarbonate enclosure. The valve controllers have been used to operate 1-inch and 1/8-inch latching valves. A field controller contains a keypad to allow entry of schedules and manual operation of the remote valves, and a liquid crystal display (LCD) for viewing status information (Figure 4c). Unique schedules for each valve are entered on the field controller and wirelessly transmitted through the mesh network to the correct valve controller, where they are stored locally. The valve controller operates autonomously based on this schedule until an update is sent by the field controller. This reduces energy-consuming communication that would be required if individual commands were transmitted for every irrigation cycle.



Figures 4a,b,c. Valve controller with 1-inch valve, components, field controller.

*Wireless communication*

When powered, the nodes automatically begin the process of forming a mesh network. This network allows messages to be passed from node to node in order to improve communication range and reliability. Commands (e.g., open or close valve) entered on the field controller keypad are transmitted to a valve controller with a particular address. The receiving valve controller executes the command provided in the message and then transmits an acknowledgement back to the field controller. Currently, this only acknowledges that the command was executed, but does not confirm, for example, that the valve actually opened properly. This feature will be explored in a later phase of development. In our tests, each node properly opened or closed the connected latching valve using an 80 ms pulse from the battery (2 A peak current).

Maximum one-hop radio range was tested under several different conditions. The wireless nodes were tested with 1/4-wave whip antennas (included with the wireless modules) and 1/2-wave dipole antennas. When using the whip antennas, nodes were tested alone and enclosed in the polycarbonate enclosure (requiring the antenna to be bent). The dipole antenna was mounted on the exterior of an enclosure. The nodes were tested under visual line-of-sight conditions (VLOS, open field) and obstructed conditions (young peach orchard) with the nodes on the ground or elevated on a non-metallic support above ground level. For each case, two or more tests were completed. The results (Table 1) show that range varied greatly depending on the node configuration and the test environment. Some test cases were combined if the resulting range was very similar. Based on these results, satisfactory range in most conditions will require a dipole antenna a half meter or more above ground level.

Table 1. Radio range under various conditions.

| View | Antenna | Elevation (m) | Enclosure | Mean range (m) |
|---|---|---|---|---|
| VLOS | whip | 0.5 | No | 51 |
| Orchard | whip | 0.5 | No | 23 |
| VLOS | whip | 0.5 | Yes | 33 |
| Orchard | whip | 0.6 | Yes | 16 |
| VLOS/Orchard | whip | 0 | Yes/No | 7 |
| VLOS | dipole | 0.8 | N/A | 98 |

| | | | | |
|---|---|---|---|---|
| Orchard | dipole | 0.8 | N/A | 72 |
| VLOS | dipole | 1.7 | N/A | 217 |
| VLOS/Orchard | dipole | 0 | N/A | 32 |

*Energy Management*

The valve controller node has a radio current of 15 mA and a sleep current of about 80 µA (radio off). To extend battery life, nodes must be in sleep-mode most of the time and only use the radio when data transfer is required. This power-cycling feature is included with the wireless module software. The nodes spend most time in sleep-mode and synchronously wake eight times per second to listen for radio activity from neighbors. If no activity is detected, the node returns to sleep. If the node were to send or receive radio messages every three minutes, the total battery consumption would be approximately 6.6 mA-h per day. This energy use must be balanced by solar panel energy production in order to ensure perpetual operation of the valve controller. Solar panel performance was tested in full sunlight and full shade conditions. A data-logger recorded open-circuit voltage in full sunlight and output current from the panel through a 10 Ω load resistor for 19 days. Peak voltage was 12.7 V and peak current was about 15 mA in full sun and 1.5 mA in shade. Integration of current over time yielded a daily production of 52 to 81 mA-h in full sun and 6 to 10 mA-h in shade. Based on these tests, the solar panel should produce adequate energy for continuous operation of the node.

Solar charging of the nickel-cadmium (Ni-Cd) battery was checked using two valve controllers, one with a solar panel and one without. They were placed outside for nine sunny days and set to transmit data messages every 15 seconds (higher rate than normal). These messages were logged every two minutes (Figure 5). The data collected included battery voltage and temperature inside the enclosure. It is evident by the voltage peaks that the solar panel charged the battery each day. However, the daily voltage low-point started to decrease after day 5. It appears that this was due to excessive heating of the enclosure. A daytime temperature over 40 °C resulted in a reduced battery voltage the following morning. This is possibly due to poor battery charging at high temperatures. Solar radiation shielding of the enclosures will be necessary to protect the circuit and battery. Small voltage fluctuations were also seen for the non-solar node. These were due to changes in battery voltage and resistance during daily temperature variation.

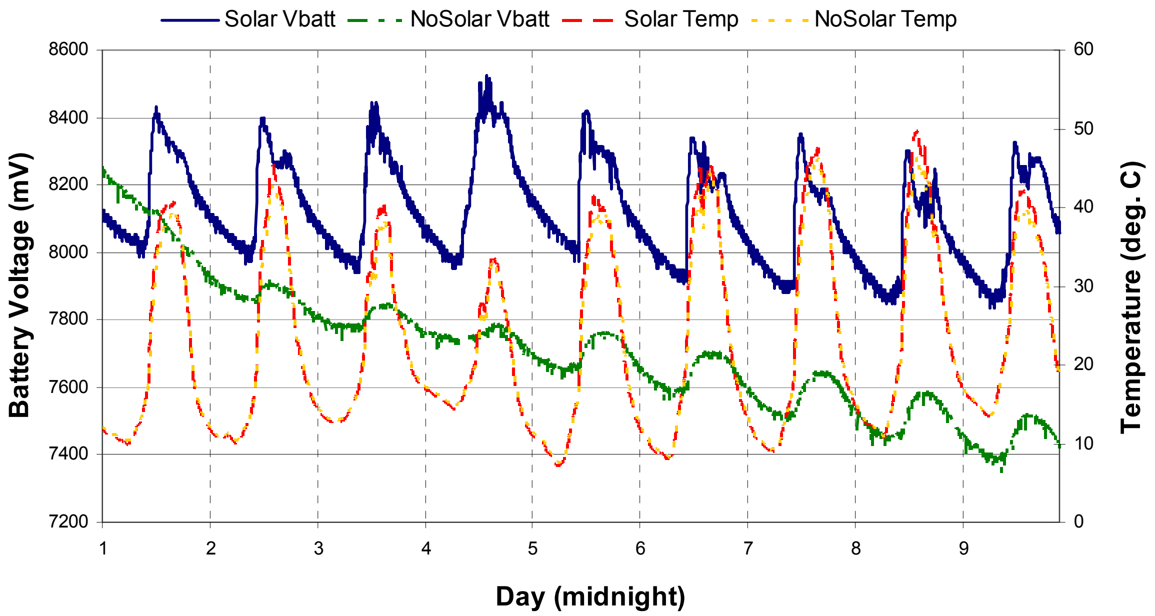


Figure 5. Battery voltage and temperature inside valve controller enclosures over 9 days.

## Project Evaluation

### *Current Progress*

In the first year of this project we considered the factors involved in spatially variable fertilizer delivery as part of task 1.1. Based on input from cooperators, it would not be practical to monitor fertigation progress using hydraulic equations. We have chosen to use EC sensors to monitor fertilizer flow (task 1.2). We have tested a simple EC sensor that can be installed in-line with a fertigation system. We are nearly ready to begin field testing of fertigation monitoring (task 1.3). We have made significant progress on development of a wireless valve controller as part of objective 2. We have tested wireless modules from three different companies and selected one from a company that has robust communication software and a strong interest in developing products for agriculture and horticulture. Specifically, we have completed task 2.1 and have nearly completed task 2.2.

### *Planned Work*

At the start of year 2 we will focus on thorough testing of EC-controlled spatially variable fertilization (*Task 1.3. Evaluate fertilizer application in field trials*). Since the wireless control system is nearly ready for deployment, we will use it to monitor fertigation, instead of modifying our previous microsprinkler system as originally stated in task 1.2. This should save us time since retrofitting the previous microsprinkler system would likely have unforeseen problems. We will install the wireless valve controller network in an outdoor test environment and evaluate its performance (*Task 2.3. Develop improved control strategies for applying water and fertilizer*). Since this system has potential applications in orchards, nurseries, greenhouses, vineyards, and landscapes, the wireless controllers will be tested in as many different environments as possible. Near the end of year 2 we will complete an economic feasibility analysis to determine at what level a wireless system would be economically viable for a grower (*Task 2.4. Evaluate the economic feasibility of a wireless valve network*).

## Outreach Activities

We presented our work at several conferences in 2007 (listed below). We met several growers and advisors that are interested in our work and we expect their input to aid in further development and commercialization of the technology.

Dahlia Greidinger Symposium
  Haifa, Israel, March 12-14, 2007
  Paper & Presentation: Wireless Network for Irrigation Valve Control
UC Precision Ag Workgroup Meeting & Miniconference
  UC Davis, June 12-13, 2007
  Presentation: Wireless valve controller network for site specific irrigation
ASABE Annual Meeting
  Minneapolis, MN, June 17-20, 2007
  Paper & Presentation: Site-Specific Water and Nutrient Application by Wireless Valve Controller Network (paper #072247)
FREP/WPHA Conference
  Tulare, CA, November 27-28, 2007
  Paper & Presentation: Wireless Valve Control Network for Fertigation Control and Monitoring