United States Department of Agriculture

Natural Resources Conservation Service

Conservation Innovation Grants

Soil Moisture-based Automatic Pulse Irrigation System for Water Conservation

Agreement Number: 69-3A75-9-162

University of Kentucky Research Foundation

Principal Investigators:
Richard Warner – Biosystems and Ag Engineering
Tim Coolong – Horticulture
John Strang – Horticulture
Tim Woods – Agriculture Economics

Period Covered: October 1, 2009 – September 30, 2011

Project End Date: September 30, 2011

March, 2013

Contents

List of Figures

List of Tables

CONSERVATION INNOVATION GRANTS
Final Report

Grantee Name: University of Kentucky Research Foundation	
Project Title: Soil Moisture-based Automatic Pulse Irrigation System for Water Conservation	
Agreement Number:69-3A75-9-162	
Project Director: Richard C. Warner	
Contact Information: Richard Warner	Phone Number: 859-257-3000 x 217 E-Mail: Richard.Warner@uky.edu
Period Covered by Report: Oct 1, 2009 – Sept. 30, 2011	
Project End Date: September 30, 2011	

Major Demonstration Project Accomplishments:

- Water usage reduction and/or yield increases clearly document the efficacy of pulse irrigation enabling producers to pay for the entire system within one growing season and still, in most situations, realize substantial profits.
- Compared to a one inch per week irrigation scheme all the demonstrated pulse irrigation systems at the UK Horticulture Farm reduced water usage with the most efficient system being the paired tensiometer pulse irrigation system (-45/-40 kPa) achieving greater than a 50% saving in water. The single tensiometer irrigation system decreased water usage by 26.7% compared to the equivalent non-pulsed system (-45/-10 kPa). There was no statistically significant reduction in crop yield.
- Compared to a well managed manual drip irrigation system, employing tensiometer readings to guide the starting and stopping of irrigation, the automatic paired tensiometer pulse irrigation system, at the UK Horticulture Farm, reduced water usage by 38.1% without any statistically significant difference in crop yield.
- Continued refinements, during this demonstration project, in the design of the pulse irrigation system resulted in three simplified systems that were implemented at the demonstration sites. These automatic pulse systems consist of 1) two tensiometers, an automatic solenoid valve, customized controller and connecting wiring, 2) a single tensiometer, latching solenoid, automatic valve, Hunter irrigation controller and connecting underground burial wiring and 3) a quasi-pulse system consisting of Watermark soil moisture sensors used in conjunction with a battery operated Watermark Electronic Module and Hunter irrigation controller.
- The simplified pulse irrigation systems can be readily adapted to current fruit and vegetable production at a cost of approximately $300 - $900, depending on equipment selection.
- No statistically significant differences in yield or vegetable quality exists comparing manual (non-pulse) irrigation to various pulse irrigation systems.
- Blueberry production at demonstration farms was either not statistically different between manual and pulse systems or resulted in a higher yield for the pulse irrigation system.

- Incorporation of weather predictions (rainfall) in the management of the pulse irrigation system can decrease water usage and increase profitability. This was a lesson learned from one of the demonstration cooperators.
- A new design for lysimeter installation, without disturbance of overlying soil, was developed and demonstrated enabling a decrease in installation time from 1 per day to 1 per hour. Design drawings and installation documentation are provided in this report. NRCS may consider recommending this technique to other investigators.
- The use of pulse irrigation resulted in no measured water flow below the crop roots, that is, water and associated nutrient losses, for the paired tensiometer pulse irrigation system with setting of -30/-25 kPa. A 9 % water loss with the single tensiometer pulse system with a setting of -45 kPa was measured. Hence, for these two systems water utilization (and potentially nutrient utilization) rates were 100% and 91%, respectively. Beside very effective water utilization the potential for nutrient leaching and possible groundwater contamination is minimized through implementation of these cost effective pulse irrigation systems.
- Outreach (technology transfer) programs conducted throughout this project, and continuing to date, were substantially greater than originally proposed in the grant application. Outreach activities included:
  - Three Horticultural Demonstration Field day/tours (attendance ~ 400)
  - Kentucky Fruit and Vegetable conferences (~160)
  - Tennessee Fruit and Vegetable Expo (16)
  - 18 Producer Events (~400)
  - ~ 30 1-on-1 consultations on irrigation management and scheduling based on pulse irrigation lessons learned
  - Modified irrigation designs and expansion to non-traditional drip irrigation applications (representative examples):
    - Doubled tomato production area without replacing the pump or main pipeline through implementation of pulse irrigation strategies
    - 6 ac of mined land energy crop production through automatic irrigation scheduling using a 7.5 kw gas generator
    - 100 ac tobacco irrigation project that decreased the pump size 3-fold and decreased the main irrigation line from 6 inches to 3 inches through incorporation of pulse irrigation-type scheduling.
  - An Extension publication on Tensiometer Installation. Note incorrect tensiometer installation was found to be the major problem with an effective pulse irrigation system due to short circuiting (preferential flow along the side of the tensiometer) causing inaccurate tensiometer moisture readings and feedback to the control system.
  - Two refereed articles.

Work performed:

Advances to the Design, Fabrication and Installation of Pulse Irrigation Systems

Original Pulse Irrigation System: The originally proposed pulse irrigation system outlined in the NRCS CIG proposal consisted of two automatic tensiometers wired to a control unit that in turn activated an irrigation control valve. The system required electric service due to solenoid power usage. The first tensiometer (dry), based on a user-specified set point (kPa setting), initiates the pulse irrigation cycle. A flip-flop timer and switches in the control unit controls the irrigation valve based on a user-specified interval, e.g. 8 to 12 minutes, until the second tensiometer (wet) reaches the user-specified lower set point which will cease operation and reset the system, awaiting the next 'on' signal. Thus an 'on' irrigation demand from the "dry" tensiometer, a repeating timer relay would toggle the irrigation valve on and off according to preset "on times' and preset "off times". This on/off cycling would continue until the "wet" tensiometer terminated irrigation.

Paired Tensiometer Pulse Irrigation System: Experience and data acquired from the original design led to a simpler irrigation controller that would be activated solely by a pair of tensiometers (dry and wet). The need for flip-flop switches was eliminated and the control circuit simplified. This pulse system consists of two tensiometers (dry and wet), a tensiometer control unit, a latched solenoid, automatic valve, connecting underground burial wiring and an irrigation controller (Figure 1). The advantage of a latched solenoid is that power is required only for on/off operation whereas with the standard solenoid used in the original proposal power is continuously needed. Thus, power requirements are substantially less with the latched solenoid enable use of solar power where electricity is not readily available.

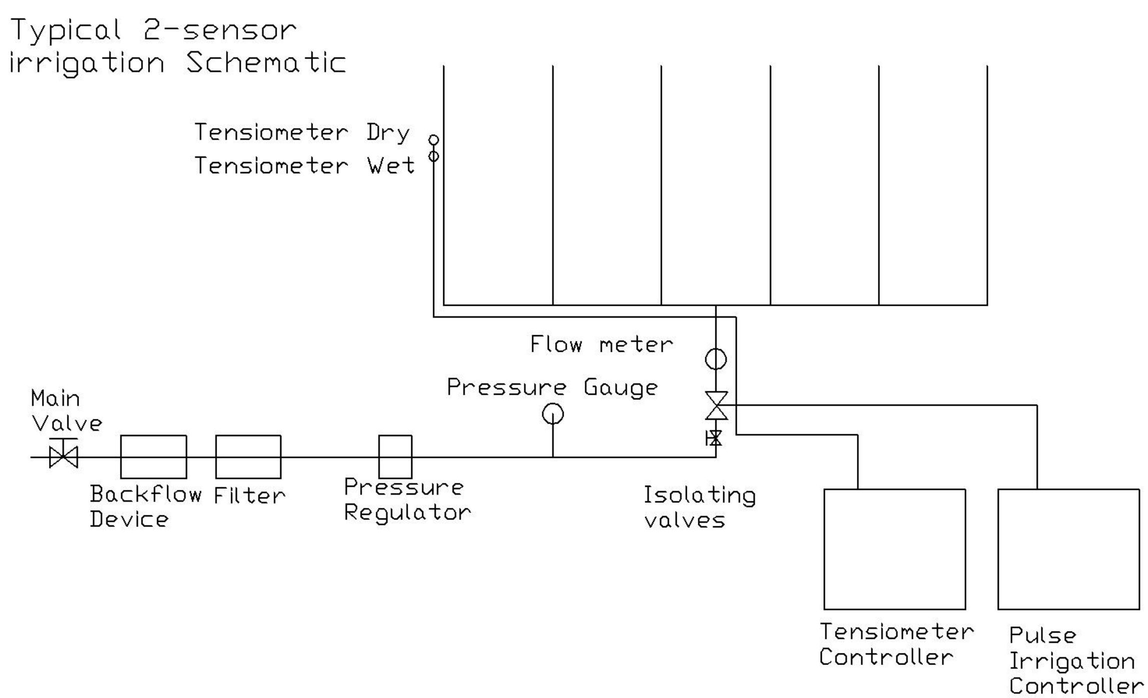

Figure 1: Paired Tensiometer Pulse Irrigation System Schematic

Single Tensiometer Hysteresis Pulse Irrigation System: A variation of paired tensiometer system is utilizing the hysteresis affect of a single tensiometer where there is a lag between sensing dryness after a wet reading was acquired. This version is effectively equivalent to having two tensiometers with a small difference in kPa setting (level of moisture) between the sensors. There is a savings due to only having one tensiometer and therefore no requirement for a dedicated tensiometer control unit. The system consists of a soil moisture sensor, latching solenoid, automatic valve, and connecting underground burial wiring (Figure 2).

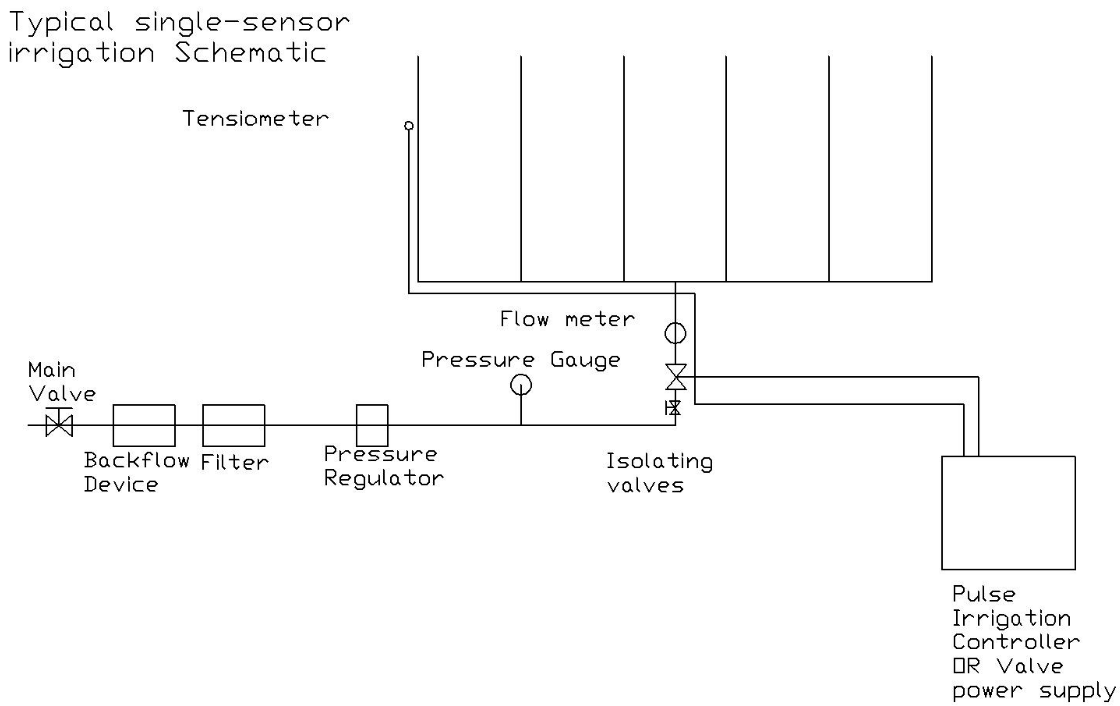

Figure 2: Single Tensiometer Hysteresis Pulse Irrigation System Schematic

Quasi-Pulse Irrigation System: Watermark soil moisture sensors were used in conjunction with a battery operated Hunter controller and valve. The intra-day on/off times (user-specified on the Hunter controller) was set to mimic pulse irrigation only during the demand time from the moisture sensors. This system proved very cost effective. It consists of two Watermark soil moisture sensors (averaged readings), latching solenoid, automatic valve, connecting wiring and a Hunter controller (Figure 3). The system only requires a 9 volt battery that lasts the entire irrigation season. The system is considered quasi-pulsed since the irrigation system operated at fixed intervals instead of operating on a continuous feedback from the soil moisture sensors. The quasi-pulse system represents a tradeoff between a true automatic feedback pulse irrigation system and ease of use.

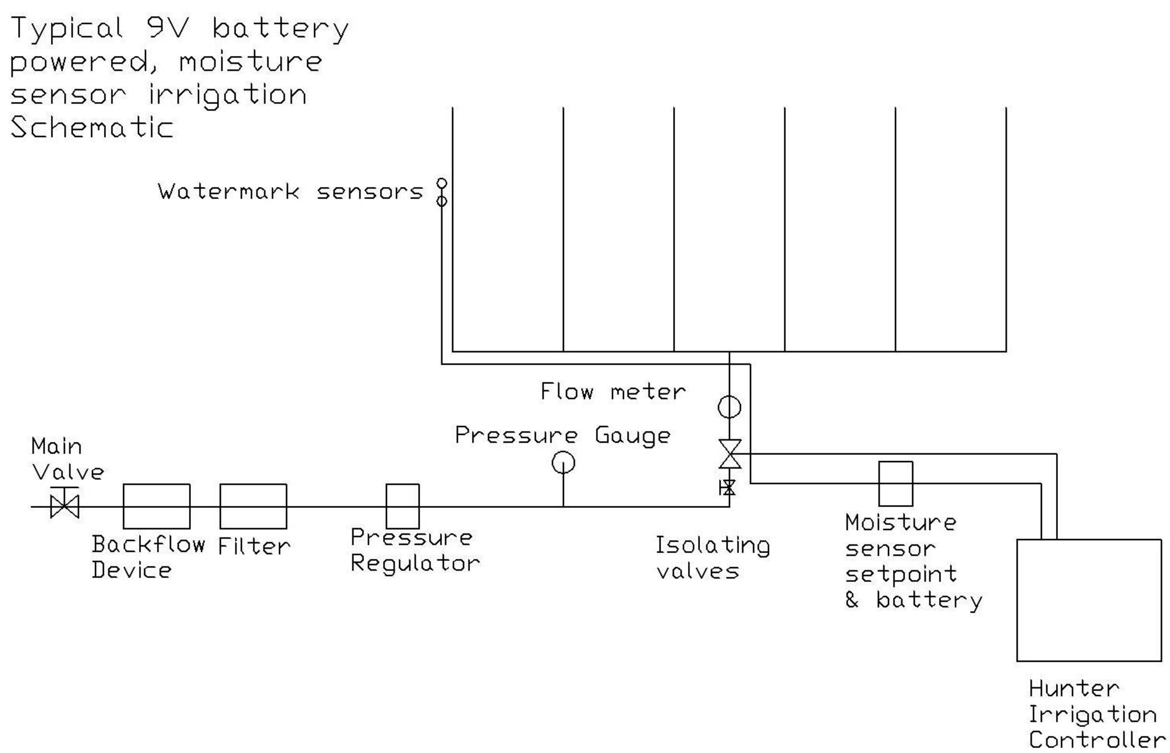

Figure 3: Quasi-Pulse Irrigation System Schematic

Water meters were installed at all demonstration sites to quantify water usage.

Lysimeter Design, Fabrication, Installation and Function:

The purpose of the lysimeter pans was to measure the quantity of water that infiltrated below the root zone for the five irrigation applications established at the primary vegetable demonstration site. Fifteen lysimeter pans were installed beneath each of the 15 rows enabling three replications for each demonstrated irrigation treatment (Figure 4). The irrigation treatments consisted of two manual (non-pulsed) and automatic two pulsed two tensiometer systems and one single tensiometer pulsed irrigation system.

Lysimeter pans were fabricated from stainless steel and filled with inert glass beads (Figure 5). Fabrication specifications are shown in Figures 6 and 7.

A trench was dug next to each row to enable excavation beneath the row without disturbance of the overlying soil. A rectangular excavator channel (tube) was constructed to create the void for the lysimeter (Figure 8). The purpose of the excavator tube was to create a space beneath the row for insertion of the lysimeter. Additionally, wooden ramps and guides were fabricated to fit into the trenches and also to provide re-active backstops (Figure 9). This was done by pressing a rectangular tube under the raised bed using a hydraulic piston (Figure 10). A 12V DC hydraulic pump was used to power the piston pushing the excavator channel into the soil and then a reverse acting cylinder/piston was used to extract the channel. A two dimensional level was placed on the guide ramp allowing a slight bias to ensure water drainage in the pan towards the outlet. Pressure developed by this pump was approximately 2000 psi and this proved adequated for the soil conditions encountered on site.

A clean cut rectangular channel, the exact length of the lysimeter pan, was developed without disturbance of the soil above. The glass bead filled pan was then inserted into the close fitting channel and then pressed upwards by inserting wedges underneath the pan. The pan outlet was connected by a short length of flexible hose to a modified rain gauge tipping bucket (Figure 11). A data logger was used to record cumulative flow.

Lysimeter pans were installed sixteen inches (+/- 2 inches) below the top of the raised bed and were centered beneath the center of the plant. The lysimeters acquired infiltrated water over an area of 28 by 3.6 inches.

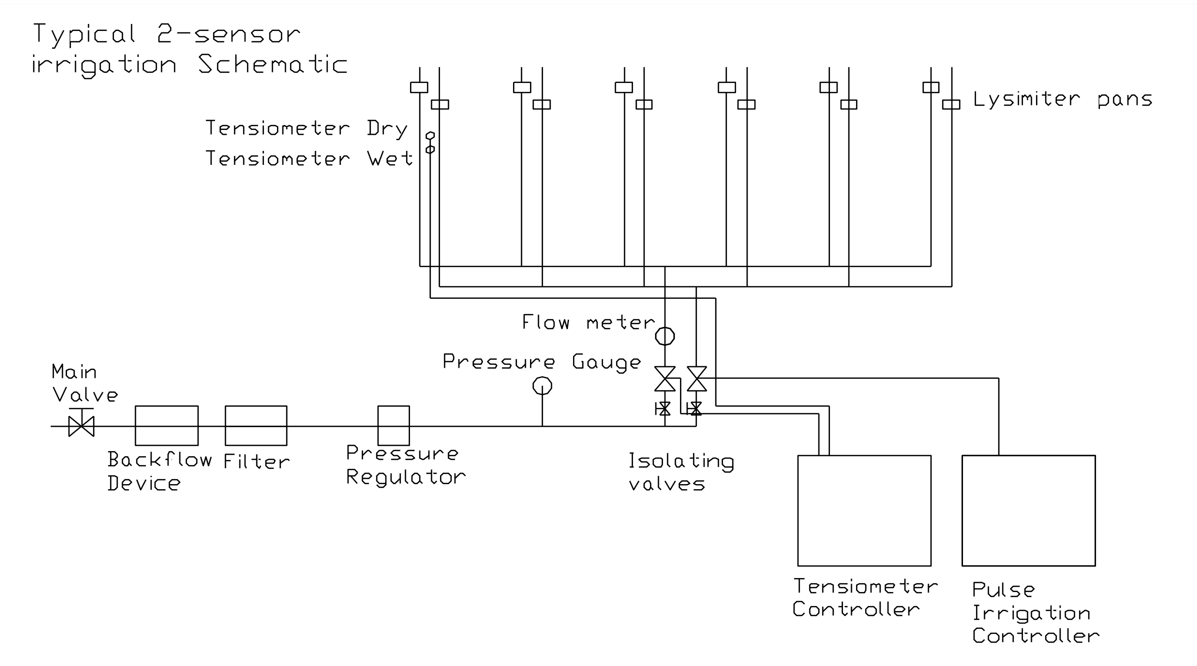

Figure 4: Typical Two Sensor Irrigation Schematic with Lysimeters

Figure 5: Lysimeter Pan Filled with Glass Beads

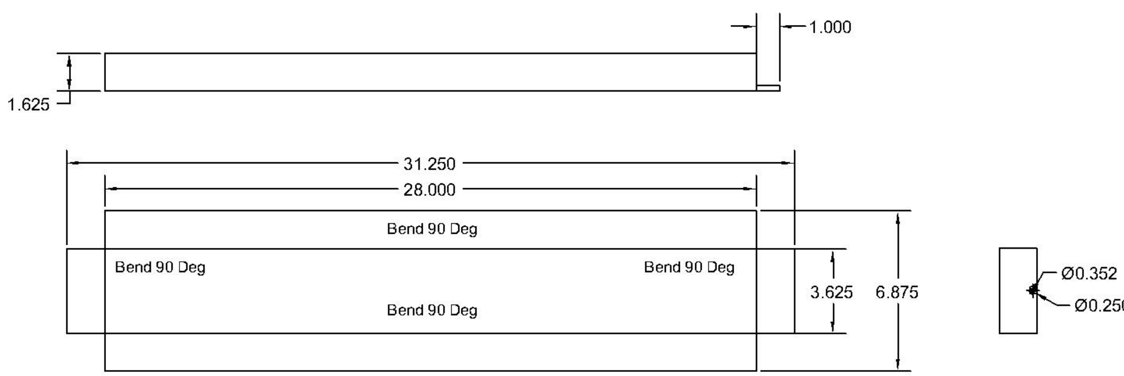

Figure 6: Lysimeter Pan Dimensions (inches)

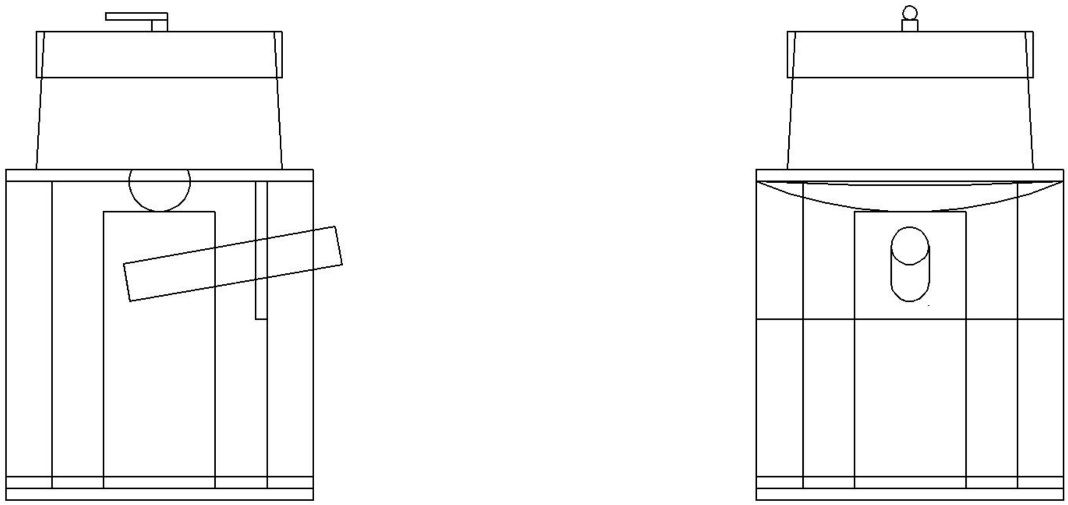

Figure 7: Lysimeter Flow Measuring Device

Figure 8: Extraction of Channel Excavator

Figure 9: Excavating Pan Channel Being Forced Under Plant Bed by Hydraulic Cylinder/Piston

Figure 10: Hydraulic Pump System

Figure 11: Connecting Drain to Pan

Vegetable Demonstration of Pulse Irrigation

Three vegetable pulse irrigation demonstration sites were established: 1) the primary site was at the University of Kentucky Horticulture Farm-Lexington, KY, and the two vegetable producer cooperators demonstration sites were: 2) D & F Farms, Science Hill, KY and 3) Cedar Point Farms, Nancy, KY. Irrigation systems were designed to enable a comparison between a well managed drip irrigation system that was manually operated based on soil moisture information provided to the producer and two or more automatic pulse irrigation systems. It is important to note that the field comparison was based on a well managed drip irrigation system and not a typical farming operation. Prior to this demonstration project producers simply applied approximately 1 in of irrigation water per week. Many producers operate their irrigation system for several hours per zone without the aid of a moisture sensor to provide feedback on soil moisture content. Comparisons to this 1-inch rule-of-thumb are also provided.

Primary Demonstration Site:

The irrigation systems installed at the primary demonstration farm featuring five alternatives (Figure 12). Two demonstrations employed paired tensiometer automatic pulsed irrigation and two employed paired tensiometers manually operated following a traditional on/off irrigation cycle (non-pulsed). The four paired tensiometer demonstrations were: 1) pulsed on/off (-30/-25 kPa) 2) pulsed (-45/-40 kPa); and automatic non-pulsed 3) -30/-10 kPa and 4) -45/-10 kPa. The fifth demonstration consisted of a single tensiometer that would automatically pulse utilizing the hysteresis affect within the sensor (-45 kPa).

Lysimeters were also installed at the primary demonstration site to acquire water that migrated below the active root zone thereby comparing the effectiveness of the alternative irrigation systems with respect to water (and nutrient) usage. The lysimeters also served as a visual exhibit for those attending field days.

Figure 12: Primary Demonstration Site with Peppers and Tomatoes

Producer Demonstration Sites:

Systems on producer sites consisted of one manual setting tensiometer controlled by farmers and their workers to emulate typical irrigation practices, and two fully automated systems (Figures 13 and 14). One automatic system delivered pulsed irrigation through paired tensiometers with settings of on/off (-50/-45 kPa). This system would come on for short periods of time but fairly frequently. The other system installed consisted of a single automated tensiometer that was set at (-50 kPa). Essentially the single tensiometer configuration would switch off once the ground wetted enough for the sensor to fall below the irrigation set point. The single tensiometer system was implemented because it would save growers money by only purchasing half the number of tensiometers, eliminate the need for the UK custom controller and simplify wiring and installation. Our intent was to trial both automated pulsed systems compared to a typical manually operated system. Crops were planted and managed at all three sites. However, crops were not harvested at Wilson's Cedar Point Farm due to a disease outbreak that coincided with extremely high temperatures in the summer of 2010 resulting in extremely low fruit set. The grower decided that it was cost prohibitive to continue to manage this field site through harvest and the demonstration was terminated prior to harvest.

Figure 13: Plot Two Weeks after Transplant at Wilson's Cedar Point Farm

Figure 14: Control Manifold at D&F Farms

Fruit Demonstration of Pulse Irrigation:

Three blueberry growers participated in the quasi-pulse automated irrigation on farm trial during the 2010 to 2011 growing seasons: 1) Blueberries of Daviess County, Utica, KY (Figure 15), 2) Reed Valley Orchard, Paris, KY(Figure 16) and 3) Caludi's Fields, Lexington, KY (Figure 17).

Figure 15: Left Row Manually Irrigated, Right Row Quasi-pulse at Blueberries of Daviess Co.

Figure 16: Left Row Quasi-pulsed, Right Row Manually Irrigated at Reed Valley Orchard

Figure 17: Rows of Blueberries at Caludi's Fields

Blueberry plants were a good choice for this demonstration as the plants have shallow root systems which are less efficient in taking up water than most other plant types. The timing of this demonstration project was very good as 2010 was the second driest season on record in 110 years and 2011 was close to the wettest season on record for Kentucky. This demonstration irrigation system was also installed on thornless semi-erect blackberries at the University of Kentucky Horticulture Farm-Lexington, KY. The primary purpose of the blackberry demonstration was to investigate pulse irrigation methods and to develop and simplify systems and procedures that would be applicable for the blueberry cooperators.

A quasi-pulse automated irrigation system (Figure 18) and a manual irrigation system (figure 19) in which the grower watered based on experience and reading a set of soil tensiometers was established at all three blueberry sites. The quasi-pulse system was selected over the continuous pulsed system used in the vegetable portion of this project because of prior experience with automated tensiometers on blackberries. Soil contact was frequently lost between the tensiometers because the blackberry roots were able to rapidly remove water in the immediate tensiometer zone necessitating manual reinstallation of the tensiometers. Additionally, the underground burial electrical wire necessary for automating the tensiometers could be expensive to run for long distances and could be cost prohibitive for many fruit growers.

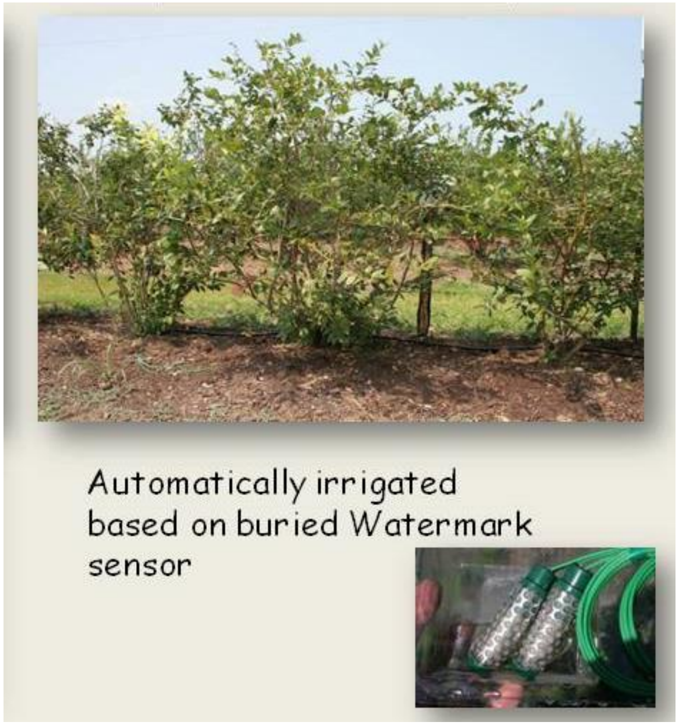

Figure 18: Quasi-pulse Irrigation System

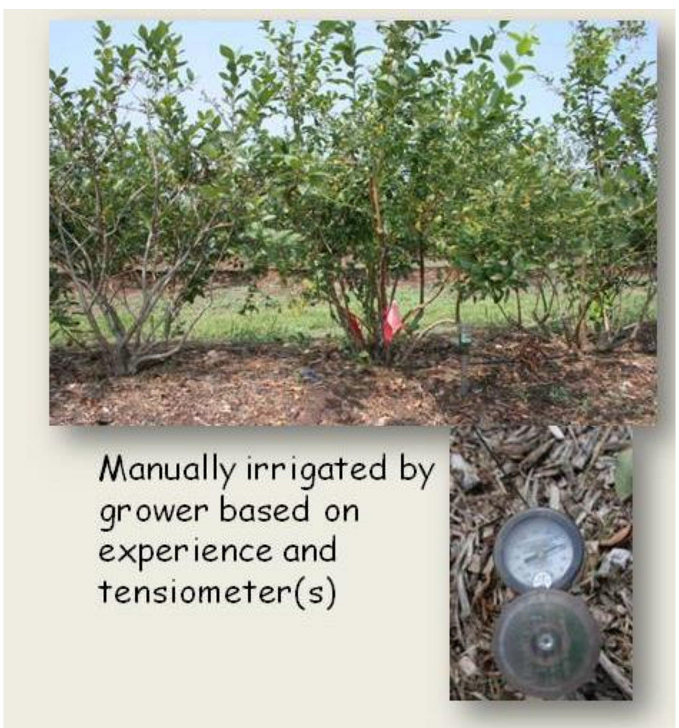

Figure 19: Manual Irrigation System

The quasi-pulse automated irrigation system consisted of a set of two Watermark sensors that were buried six inches apart laterally, located 12 inches from the plant base and 12 inches from the nearest 1 gal/hour emitter. The average moisture content, provided by the two sensors, controlled the irrigation system through the Watermark Electronic Module and Hunter controller. The Watermark WEM-B battery powered module can be set at an user-specified moisture content and in turn provides a signal to a Hunter single station irrigation controller to activate the solenoid valve and operate the system for a user-defined irrigation interval.

The Watermark Electronic Module had moisture level settings ranging from 1 (wet) to 9 (dry). A setting of 5-9 corresponding to 35-80 kPa was recommended for most shrubs and ground covers. The Hunter controller was programmed to query the Watermark controller eight times per day at three hour intervals for the demonstration sites. If the average soil moisture level of the two Watermark sensors was above the pre set level (dry), the system would activate the solenoid and irrigate for a period of two hours and 55 minutes (user-specified). If the soil moisture content reached the pre-set level no irrigation would be proved for the subsequent 3-hour interval. The quasi-pulse terminology is used since the moisture sensors simply are used to turn on the irrigation system for a user-defined interval instead of providing a continuous feedback to the controller such as is accomplished by the tensiometer pulse irrigation configurations.

The averaged two sensor system was viewed by Dr. Strang as providing an enhanced measurement of soil moisture over a wider area at a six inch depth compared to the tensiometers that utilized a wet and dry sensor at two locations. Advantages of utilizing the Watermark sensors (Irrometer Company, Inc.) compared to automatic tensiometers is that they operate over a wider range of moisture contents 0-200 kPa, did not break contact with the soil as experienced with tensiometers prior to this study with blackberries and can be installed and left for a number of seasons which is especially useful for perennial fruit crops. This system operated for the entire season on a 9 volt battery making it very reliable and economical.

Soil moisture was measured beneath a manually irrigated plant and a quasi-pulse irrigated plant using ECH_2O EC-5 Decagon Soil Moisture Sensors (Decagon Devices, Inc.) at each demonstration farm. Sensors were inserted at 6 inch and 12 inch depths situated 12 inches from the plant base and 12 inches from a drip emitter on a manually and a quasi-pulse irrigated plant. These sensors were monitored by a data logger that took readings every two hours.

Rainfall was monitored at the Blueberries of Davis County and Reed farms by a tipping bucket and data logger that logged each 0.01 inch of rainfall and by an automated Mesonet weather Station located at the Horticultural Farm, Lexington, KY across the street from the Caludi farm. Data loggers also monitored both the manual system operation and quasi-pulse system operations.

All plantings were drip irrigated using one gallon per hour emitters. The Blueberries of Davis County and Reed sites were set up such that one row of blueberry plants was manually irrigated and an adjacent row was quasi-pulse irrigated. The Caludi planting was set up with a manually irrigated drip line and a quasi-pulse drip line in each row. Groups of three plants in each row were then either irrigated manually or quasi-pulse.

Irrigation systems were activated at the three blueberry farms in early June of 2010 and the Watermark Electronic Modules were all set at an irrigation level of 5 which corresponded to about 35 kPa. After approximately a month of operating the irrigation system it was determined that this setting was too wet and all modules were adjusted to a level of 7 corresponding to about 57 kPa for the remainder of the project.

The soil at the Blueberries of Davis County and Reed Valley Orchard demonstration sites was silt clay, which retained water better than the silt loam at the Caludi site. The Davis County and Reed blueberry plantings were mulched with sawdust and wood chips respectively, while the Caludi site was not mulched. All cooperators had extensive blueberry growing experience and excellent weed control was maintained over the project duration.

Blueberry shoot growth measurements were taken the fall of 2010 and fruit were harvested during the summer of 2011. Yields in 2011 were primarily based on the irrigation regimes in 2010.

Results

Accomplishments – Design, Installation of Minimal Cost Pulse and Quasi-pulse Irrigation Systems

<u>Installation:</u>

A variety of pulse and quasi-pulse irrigation systems was designed, fabricated and installed to demonstrate alternative systems for cooperators and participants in field days, tours, short course presentations, etc. The paired tensiometer pulse irrigation system and single hysteresis pulse irrigation systems were demonstrated at vegetable cooperators and the quasi-pulse system demonstrated at the blueberry cooperators. Systems were available at the primary demonstration site. Systems functioned as expected providing irrigation on demand based on user-specified moisture levels.

Installation of five alternative pulse irrigation systems required approximately three weeks at the primary demonstration site. The design was relatively complicated and was the first attempt at such a system installation. Installations at cooperators required approximately one to two days per site excluding travel.

With the simplifications learned during this project it is expected that a producer can install the pulse irrigation components of a drip irrigation system in approximately two hours. Additional time will be needed to run underground burial wire depending on the location of a power source, irrigation controller and valves. For the quasi-pulse system installation will normally occur in the field near the crop. Installation is very simple and can be accomplished in approximately one hour. Both the Watermark Electronic Module and Hunter controller each operate on a 9 volt battery and the Watermark moisture sensors are easily installed.

Tensiometer placement proved to be the most difficult part of the installation process for the paired and single tensiometer systems. If incorrectly installed the system will not function as anticipated. Water will migrate along the side of the tensiometer and wet the porous cup resulting in a false reading. That is, the entire soil matrix will not be irrigated yet the moisture sensor will falsely indicate a wet condition and terminate irrigation. Since installation of the tensiometer is such a critical component an extension publication entitled Tensiometer Installation (Coolong and Surendran, 2011) was written.

Comparison of Actual Accomplishments to Proposal Project Goals

The project proposal stated that the proposed pulse irrigation system would be installed at all sites. Based on experience gained in the project's first year pulse irrigation systems were significantly advanced and simplified. Three alternative systems were developed and utilized at the primary demonstration farm and at cooperator farms. The alternative pulse- and quasi-pulse irrigation systems had the advantage of reducing cost by approximately 50%, reduced installation time and were easier to operate. Hence, the project far exceeded expectations of the system detailed in the proposal.

<u>Components and Cost of Pulse and Quasi-pulse Irrigation Systems</u>

After exploring, testing, and modifying numerous alternative designs during the initial year of the project three very cost effective pulse irrigation systems were developed (Table 1). Cost ranged from approximately $300 to $900, plus miscellaneous components, per system. These costs include an optional water meter which is recommended for all systems in order to track water usage and a Watermark meter for the quasi-pulse system to read the soil moisture from the sensors. Only one Watermark meter is needed. Without the optional equipment, costs range from $200 to $800.

Table 1: Pulse Irrigation Systems Component and Cost including Optional Water Meter and Watermark Meter (minimum cost variance excluding common fittings, installation, etc.)

Item	**Cost Estimate**	**Paired Tensiometers**		**Single Tensiometer**		**Quasi-Pulse**	
Hunter controller[1]	90			1	$90	1	$90
UK Custom controller[2]	550	1	$550				
Water meter[3]	105	1	$105	1	$105	1	$105
Hunter PGV valve[4]	15	1	$15	1	$15	1	$15
Tensiometer	95	2	$190	1	$95		
Watermark system[5]	200					1	$200
Watermark meter[6]	330					1	$330
		$860.00		**$305.00**		**$740.00**	

Notes:
1 Single valve controller (two & four valve options available at additional cost)
2 Custom circuit design for two tensiometers (UK designed & fabricated)
3 Optional - to track water consumption
4 Based on a 1" PVC valve
5 Two sensor system with battery controller (Type WEM-B)
6 Optional - to acquire moisture levels from watermark sensors in Quasi-pulse

Lysimeter Results:

The use of pulse irrigation, at the UK Horticulture Farm, resulted in no measured water flow below the vegetable crop roots for the paired tensiometer pulse irrigation system with start/stop setting of -30/-25 kPa. A 9 % water loss with the single tensiometer pulse system with a setting of -45 kPa was measured. Hence, for these two systems water utilization (and potentially nutrient utilization) rates were 100% and 91%, respectively. Beside very effective water utilization the potential for nutrient leaching and possible groundwater contamination is minimized through implementation of these cost effective pulse irrigation systems.

Comparison of Actual Accomplishments to Proposal Project Goals

A new design for lysimeter installation, without disturbance of overlying soil, was developed and demonstrated enabling a decrease in installation time from 1 per day to 1 per hour. Design drawings and installation documentation are provided in this report. NRCS may consider recommending this technique to other investigators. The development of lysimeter installation technology was significantly advanced beyond that specified in the project proposal.

Accomplishments – Vegetable Demonstration:

The demonstration sites proved valuable in accomplishing our goal to develop and demonstrate water saving irrigation technologies through pulse irrigation.

University of Kentucky Primary Demonstration Site:

The paired tensiometer pulsed system, at the University of Kentucky Horticulture Farm showed a water savings over the paired tensiometer (non-pulsed) manual irrigation system. It should be noted that the manual system was considered a well managed drip irrigation system in that tensiometer readings were used to indicate when irrigation water should be applied and when to turn off the system. In contrast, many producers do not use tensiometers or other moisture probes but simple operate an irrigation system to apply approximately one inch of water per week. Based on a 14 week growing season 380,000 gal/ac would be applied using the 1 inch/week irrigation rule-of-thumb. Thus, compared to such an irrigation scheme all the demonstrated systems reduced water usage with the most efficient paired tensiometer pulse irrigation system (-45/-40 kPa) achieving greater than a 50% saving in water (Table 2). The single tensiometer irrigation system decreased water usage by 26.7% compared to the equivalent non-pulsed system (-45/-10 kPa). There was no statistically significant reduction in crop yield.

Compared to a well managed manual drip irrigation system (non-pulsed, -45/-10 kPa), employing tensiometer readings to guide the starting and stopping of irrigation, the paired tensiometer pulse irrigation system (pulsed -45/-40 kPa), at the UK Horticulture Farm, reduced water usage by 38.1% without any statistically significant difference in crop yield.

Table 2: University of Kentucky Primary Demonstration Site Water Usage Results

Treatment	**Yield (marketable) (lbs/acre)**	**Water Use (gallon/acre)**	**Pulse versus 1 in/ac/week (%)**
Non Pulse (-30/-10 kPa)	17,550	247,390	34.9 less
Non Pulse (-45/-10 kPa)	16,270	292,290	23.1 less
Pulse (-30/-25 kPa)	13,740	204,700	46.1 less
Pulse (-45/-40 kPa)	14,800	180,880	52.4 less
Single tensiometer pulse (-45 kPa)	16,410	217,160	42.9 less

D & F Farms, Science Hill, KY:

Yields and water usage data were obtained from 400 foot demonstration sections at D & F farms (Table 3):

Table 3: D & F Farms Results

System	Yield	Water Usage
Manual operated system	58,950 lbs/acre	291,168 gallons/acre
Two tensiometer pulsed system	56,250 lbs/acre	408,366 gallons/acre
Single tensiometer pulsed system	60, 534 lbs/acre	350,334 gallons/acre

Yields were comparable between all three systems, with the single tensiometer pulsed system having the highest yields. Water usage was actually lowest in the manually operated system and highest in the paired tensiometer system. This was unexpected since previous work, and results from the UK Horticulture demonstration project showed that the pulse irrigation tensiometer based system was preferred to a manual system. However in this instance after meeting with the grower and discussing his irrigation strategies it was determined that irrigation water applications were based on the weather forecast. In many cases the grower knew that rain was forecast for the following day and would avoid irrigating for this reason. The automated pulse system could not predict rain and on several occasions irrigated when soil moisture reached the threshold level. In addition, conversations with the grower indicated that he did modify his irrigation management slightly and avoided long irrigation events in favor of shorter ones implementing a quasi-pulse system for manual irrigation management. The primary lesson learned was that irrigation system efficiency can be increased for the pulse irrigation system through augmenting an over-ride capability based on user-input of the weather forecast.

Wilson's Cedar Point Farm:

The second grower demonstration site, Wilson's Cedar Point Farm, did not harvest tomatoes but initial water monitoring demonstrated an improvement in irrigation management with the automated pulse irrigation system. In this instance irrigation events were shorter in the automated pulsed system. During the month of June while plants were growing and setting initial fruit the manual system irrigation was run for 10 hours and 45 minutes (20,900 gallons/acre) while the paired pulsed tensiometer system ran for only a total of 3.5 hours (6,800 gallons/acre). Here the automated pulsed system was useful in terminating irrigation once the desired level of soil moisture was reached and not initiating irrigation when unnecessary. In this particular location the grower's irrigation crew managed irrigation in a tradition manner with infrequent long irrigations. Compared to such traditional irrigation management a substantial savings in water usage could have been achieved utilizing the paired tensiometer pulse irrigation system.

Based on these results and previous data growers could benefit from switching to a system where they water more frequently and for less time, similar to Mr. Faulkner of D & F farms. In addition, although the automated system may not be for everyone, one of the biggest benefits of automation is the ability to turn off a system when the soil is appropriately wetted. Growers could use a modified system that is started manually but turns off automatically. This would prevent long duration irrigations and allow the grower to tend to other activities on the farm.

The initial results of the ongoing trials were discussed at the Horticulture Research Farm Field day on July, 22 2010. This was an important avenue for outreach. Two tours came by the irrigation management stop and the pulsing irrigation was discussed with the attendees as well as water conservation techniques that can be used in farming.

Economic Evaluation of the Alternative Irrigation Systems for Tomatoes and Peppers

Capital costs associated with different variations of the pulse irrigation systems were low, approximately \$300 to \$900 as noted in Table 1. Two automated pulse irrigation systems were examined, an elaborate (paired tensiometer automatic pulse) and a low cost (single tensiometer) system, for the purpose of determining sensitivity to other variables impacting net returns. Both systems were compared with well managed manual irrigation strategies utilized during tomato and poblano pepper production in 2009 and 2010. A partial budgeting framework was used to analyze the change in net returns due to the adoption of each automated system. In addition, sensitivity analyses were conducted to explore the influence of water and crop prices on the profitability of the automated pulse irrigation systems.

The factors that directly influenced the profitability of automated pulse irrigation systems included the cost of the irrigation system, water savings, yield impacts, crop prices, and irrigation labor reductions. The total investment cost for the elaborate automated pulse irrigation system was \$900 and \$300 for the low cost system. The costs were annualized using the straight-line depreciation method plus the opportunity cost of capital represented by the average value times the interest rate (Equation 1).

$$(1) \quad \left(\frac{Total\ Investment - Salvage\ Value}{Useful\ Life}\right) + \left(\frac{(Total\ Investment + Salvage\ Value) * Interest\ Rate}{2}\right)$$

There was an assumed seven year useful life and no salvage value for the purposes of estimating an annualized cost. The opportunity cost of capital was calculated using a 6% interest rate. When annualized, the elaborate and low cost automated pulse irrigation systems cost \$156 and \$52, respectively. In addition, a repair and maintenance charge was calculated assuming a cost of 5% of the total investment. Therefore the total annual cost of the elaborate and low cost automated pulse irrigation systems were \$201 and \$67, respectively.

Water savings were determined by observations reported in the on-farm experiments. The base line water price assumed was \$0.0042452/gal which corresponded to the current price for city water at South Farm in Lexington, KY. Water costs can vary substantially by location, depending on municipal rates or well access. The yield impacts from irrigation strategies used in this analysis were also determined by the on-farm experiments reported earlier. Tomato and poblano pepper prices were determined from the Fairview Auction using #1 tomato and specialty pepper prices which were averaged over the reported harvest dates (2009 Tomatoes: Aug. 4 - Sept. 9; 2010 Tomatoes: Aug. 16 – Sept. 13; 2010 Poblano peppers: Aug. 16 – Sept. 7) to approximate Kentucky market conditions at the time. In addition, irrigation labor costs of \$15/hr and 24 hrs/acre were assumed for well managed manual irrigation strategies. Irrigation labor costs were cut in half for the automated pulse systems since it was assumed the producer would likely check to see if the irrigation system turned on and was operating properly but would let it automatically turn off.

The yield and water saving results varied by crop, year, and irrigation strategy throughout the study which suggested some variability in the corresponding net returns. Net returns are summarized for the tomatoes and peppers based on observed corresponding yield and water outcomes, but also for a range of assumptions for product market price and water prices. Net income sensitivity for each irrigation strategy is summarized in Tables 4a-9d.

Due to the extreme amount of additional water applied to tomatoes in 2009 under the -30/-25 irrigation strategy, automated pulse irrigation would not be profitable regardless of water or tomato prices. On the other hand, since -45/-40 automated pulse strategy both saved water and had greater yields, both low cost and elaborate automated pulse irrigations systems were profitable. The low cost automated pulse system resulted in the greatest increase in net returns above the well managed manual irrigation strategy as much as $3,200/ac for high tomato and water prices.

For tomatoes produced in 2010, automated pulse irrigation never was profitable regardless of water or tomato prices, even though the automated pulse system saved water under both -35/30 and -45/-40 strategies. Under the best performing strategy (-45/-40) using the low cost system and at the lowest tomato price and highest water price, in order to break-even and pay for the investment, an additional 15,000 gal./ac was required to be saved. Reasons for relative yield and water use differences were discussed earlier.

For poblano peppers produced in 2010, low cost automated pulse irrigation was always profitable and returned as much as $2,400/ac for high pepper and water prices under the -50/-45 strategy. The elaborate system was profitable when pepper prices were at or above the mean for the majority of irrigation strategies. Similar to the low cost automated pulse irrigation system, the -50/-45 strategy performed the best and returned $1,700/ac for high water and pepper prices.

Market price variation for tomatoes and peppers appears to play a more significant role in the net return compared to variation in water cost. It was clear that return on investment was most significantly reduced or negative when the pulse irrigation trials showed lower yields. Products evaluated in this study were higher-value crops. Therefore, potential yield impacts of pulse irrigation adoption are important considerations associated with the economics of adoption under these conditions.

In summary, water savings plays a lesser role in determining the profitability of automated pulse irrigation for tomatoes and peppers due to prevailing low water prices, at least in Kentucky. However, the automated pulse irrigation system is an inexpensive insurance policy and could pay for itself immediately, and did under many of the conditions observed during these on-farm and station research trials. Finally, preliminary evidence suggests automated pulse irrigation becomes more profitable under dryer environmental conditions.

Table 4a. Change in net returns per acre for operating a low cost automatic pulse irrigation system at -30/-25 when compared to a well managed manual irrigation system at a rate of -30/-10 for 2009 tomato production in Kentucky under various water and tomato prices.

		Tomato Price				
		-50%	-25%	Base[1]	+25%	+50%
Water Prices	Base[2]	($88)	($115)	($142)	($169)	($195)
	+25%	($126)	($153)	($179)	($207)	($233)
	+50%	($164)	($191)	($216)	($245)	($271)
	+75%	($202)	($229)	($253)	($283)	($309)
	+100%	($240)	($267)	($290)	($321)	($347)

[1] A base tomato price of $14.94 for a 25 lb box was determined from the average prices at Fairview Auction from August 4th 2009 to September 8th, 2009.
[2] A base water price of $0.0042452/gal was used that represented city water for Lexington, KY.

Table 4b. Change in net returns per acre for operating a low cost automatic pulse irrigation system at -45/-40 when compared to a well managed manual irrigation system at a rate of -45/-10 for 2009 tomato production in Kentucky under various water and tomato prices.

		Tomato Price				
		-50%	-25%	Base[1]	+25%	+50%
Water Prices	Base[2]	$1,221	$1,666	$2,109	$2,554	$2,997
	+25%	$1,276	$1,721	$2,163	$2,609	$3,052
	+50%	$1,331	$1,776	$2,219	$2,664	$3,107
	+75%	$1,386	$1,831	$2,275	$2,719	$3,162
	+100%	$1,441	$1,886	$2,331	$2,774	$3,217

[1] A base tomato price of $14.94 for a 25 lb box was determined from the average prices at Fairview Auction from August 4th 2009 to September 8th, 2009.
[2] A base water price of $0.0042452/gal was used that represented city water for Lexington, KY.

Table 5a. Change in net returns per acre for operating an elaborate automatic pulse irrigation system at -30/-25 when compared to a well managed manual irrigation system at a rate of -30/-10 for 2009 tomato production in Kentucky under various water and tomato prices.

		Tomato Price				
		-50%	-25%	Base[1]	+25%	+50%
Water Prices	Base[2]	($222)	($249)	($276)	($303)	($329)
	+25%	($260)	($286)	($313)	($341)	($367)
	+50%	($298)	($324)	($350)	($379)	($405)
	+75%	($336)	($362)	($387)	($417)	($443)
	+100%	($374)	($400)	($424)	($455)	($481)

[1] A base tomato price of $14.94 for a 25 lb box was determined from the average prices at Fairview Auction from August 4th 2009 to September 8th, 2009.
[2] A base water price of $0.0042452/gal was used that represented city water for Lexington, KY.

Table 5b. Change in net returns per acre for operating an elaborate automatic pulse irrigation system at -45/-40 when compared to a well managed manual irrigation system at a rate of -45/-10 for 2009 tomato production in Kentucky under various water and tomato prices.

		Tomato Price				
		-50%	-25%	Base[1]	+25%	+50%
Water Prices	Base[2]	$1,087	$1,532	$1,975	$2,420	$2,863
	+25%	$1,142	$1,587	$2,030	$2,475	$2,918
	+50%	$1,198	$1,642	$2,085	$2,530	$2,973
	+75%	$1,253	$1,697	$2,140	$2,585	$3,028
	+100%	$1,308	$1,752	$2,195	$2,640	$3,083

[1] A base tomato price of $14.94 for a 25 lb box was determined from the average prices at Fairview Auction from August 4th 2009 to September 8th, 2009.
[2] A base water price of $0.0042452/gal was used that represented city water for Lexington, KY.

Table 6a. Change in net returns per acre for operating a low cost automatic pulse irrigation system at -30/-25 when compared to a well managed manual irrigation system at a rate of -30/-10 for 2010 tomato production in Kentucky under various water and tomato prices.

		Tomato Price				
		-50%	-25%	Base[1]	+25%	+50%
Water Prices	Base[2]	($1,073)	($1,730)	($2,387)	($3,046)	($3,704)
	+25%	($1,041)	($1,698)	($2,355)	($3,014)	($3,675)
	+50%	($1,009)	($1,666)	($2,323)	($2,982)	($3,643)
	+75%	($977)	($1,634)	($2,291)	($2,950)	($3,611)
	+100%	($945)	($1,602)	($2,259)	($2,918)	($3,579)

[1] A base tomato price of $17.27 for a 25 lb box was determined from the average prices at Fairview Auction from August 16th 2010 to September 13th, 2010.
[2] A base water price of $0.0042452/gal was used that represented city water for Lexington, KY.

Table 6b. Change in net returns per acre for operating a low cost automatic pulse irrigation system at -45/-40 when compared to a well managed manual irrigation system at a rate of -45/-10 for 2010 tomato production in Kentucky under various water and tomato prices.

		Tomato Price				
		-50%	-25%	Base[1]	+25%	+50%
Water Prices	Base[2]	($270)	($533)	($797)	($1,061)	($1,324)
	+25%	($234)	($497)	($761)	($1,025)	($1,288)
	+50%	($198)	($461)	($725)	($989)	($1,252)
	+75%	($162)	($425)	($689)	($953)	($1,216)
	+100%	($126)	($389)	($653)	($917)	($1,180)

[1] A base tomato price of $17.27 for a 25 lb box was determined from the average prices at Fairview Auction from August 16th 2010 to September 13th, 2010.
[2] A base water price of $0.0042452/gal was used that represented city water for Lexington, KY.

Table 7a. Change in net returns per acre for operating an elaborate automatic pulse irrigation system at -30/-25 when compared to a well managed manual irrigation system at a rate of -30/-10 for 2010 tomato production in Kentucky under various water and tomato prices.

		Tomato Price				
		-50%	-25%	Base[1]	+25%	+50%
Water Prices	Base[2]	($1,206)	($1,864)	($2,521)	($3,180)	($3,838)
	+25%	($1,174)	($1,832)	($2,489)	($3,148)	($3,806)
	+50%	($1,142)	($1,800)	($2,457)	($3,116)	($3,774)
	+75%	($1,110)	($1,768)	($2,425)	($3,084)	($3,742)
	+100%	($1,078)	($1,736)	($2,393)	($3,052)	($3,710)

[1] A base tomato price of $17.27 for a 25 lb box was determined from the average prices at Fairview Auction from August 16th 2010 to September 13th, 2010.
[2] A base water price of $0.0042452/gal was used that represented city water for Lexington, KY.

Table 7b. Change in net returns per acre for operating an elaborate automatic pulse irrigation system at -45/-40 when compared to a well managed manual irrigation system at a rate of -45/-10 for 2010 tomato production in Kentucky under various water and tomato prices.

		Tomato Price				
		-50%	-25%	Base[1]	+25%	+50%
Water Prices	Base[2]	($403)	($667)	($930)	($1,195)	($1,458)
	+25%	($367)	($631)	($895)	($1,159)	($1,422)
	+50%	($331)	($595)	($859)	($1,123)	($1,386)
	+75%	($295)	($559)	($823)	($1,087)	($1,350)
	+100%	($259)	($523)	($787)	($1,051)	($1,314)

[1] A base tomato price of $17.27 for a 25 lb box was determined from the average prices at Fairview Auction from August 16th 2010 to September 13th, 2010.
[2] A base water price of $0.0042452/gal was used that represented city water for Lexington, KY.

Table 8a. Change in net returns per acre for operating a low cost automatic pulse irrigation system at -30/-25 when compared to a manual irrigation system at a rate of -50/-10 for 2010 poblano pepper production in Kentucky under various water and pepper prices.

		Pepper Price				
		-50%	-25%	Base[1]	+25%	+50%
Water Prices	Base[2]	$336	$512	$686	$861	$1,035
	+25%	$304	$480	$655	$829	$1,003
	+50%	$272	$448	$623	$797	$971
	+75%	$240	$416	$591	$765	$939
	+100%	$208	$352	$559	$733	$907

[1] A base poblano pepper price of $3.68 a peck was determined from the average prices at Fairview Auction from August 16th 2010 to September 7th, 2010.
[2] A base water price of $0.0042452/gal was used that represented city water for Lexington, KY.

Table 8b. Change in net returns per acre for operating a low cost automatic pulse irrigation system at -40/-35 when compared to a manual irrigation system at a rate of -50/-10 for 2010 poblano pepper production in Kentucky under various water and pepper prices.

		Pepper Price				
		-50%	-25%	Base[1]	+25%	+50%
Water Prices	Base[2]	$251	$423	$593	$764	$935
	+25%	$200	$372	$543	$713	$884
	+50%	$149	$321	$492	$662	$833
	+75%	$98	$270	$441	$611	$782
	+100%	$47	$219	$390	$560	$731

[1] A base poblano pepper price of $3.68 a peck was determined from the average prices at Fairview Auction from August 16th 2010 to September 7th, 2010.
[2] A base water price of $0.0042452/gal was used that represented city water for Lexington, KY.

Table 8c. Change in net returns per acre for operating a low cost automatic pulse irrigation system at -50/-45 when compared to a manual irrigation system at a rate of -50/-10 for 2010 poblano pepper production in Kentucky under various water and pepper prices.

		Pepper Price				
		-50%	-25%	Base[1]	+25%	+50%
Water Prices	Base[2]	$689	$1,112	$1,533	$1,955	$2,376
	+25%	$622	$1,045	$1,467	$1,888	$2,309
	+50%	$555	$978	$1,400	$1,821	$2,242
	+75%	$488	$911	$1,333	$1,754	$2,175
	+100%	$421	$844	$1,199	$1,687	$2,108

[1] A base poblano pepper price of $3.68 a peck was determined from the average prices at Fairview Auction from August 16th 2010 to September 7th, 2010.
[2] A base water price of $0.0042452/gal was used that represented city water for Lexington, KY.

Table 8d. Change in net returns per acre for operating a low cost automatic pulse irrigation system at -60/-55 when compared to a manual irrigation system at a rate of -50/-10 for 2010 poblano pepper production in Kentucky under various water and pepper prices.

		Pepper Price				
		-50%	-25%	Base[1]	+25%	+50%
Water Prices	Base[2]	$570	$853	$1,135	$1,417	$1,700
	+25%	$543	$826	$1,108	$1,390	$1,673
	+50%	$516	$799	$1,081	$1,363	$1,646
	+75%	$489	$772	$1,054	$1,336	$1,619
	+100%	$462	$745	$1,027	$1,309	$1,592

[1] A base poblano pepper price of $3.68 a peck was determined from the average prices at Fairview Auction from August 16th 2010 to September 7th, 2010.
[2] A base water price of $0.0042452/gal was used that represented city water for Lexington, KY.

Table 9a. Change in net returns per acre for operating an elaborate automatic pulse irrigation system at -30/-25 when compared to a manual irrigation system at a rate of -50/-10 for 2010 poblano pepper production in Kentucky under various water and pepper prices.

		Pepper Price				
		-50%	-25%	Base[1]	+25%	+50%
Water Prices	Base[2]	$202	$378	$553	$727	$902
	+25%	$170	$347	$521	$695	$870
	+50%	$138	$315	$489	$663	$838
	+75%	$106	$283	$457	$631	$806
	+100%	$74	$251	$425	$599	$774

[1] A base poblano pepper price of $3.68 a peck was determined from the average prices at Fairview Auction from August 16th 2010 to September 7th, 2010.
[2] A base water price of $0.0042452/gal was used that represented city water for Lexington, KY.

Table 9b. Change in net returns per acre for operating an elaborate automatic pulse irrigation system at -40/-35 when compared to a manual irrigation system at a rate of -50/-10 for 2010 poblano pepper production in Kentucky under various water and pepper prices.

		Pepper Price				
		-50%	-25%	Base[1]	+25%	+50%
Water Prices	Base[2]	$117	$289	$460	$630	$801
	+25%	$66	$238	$409	$579	$750
	+50%	$15	$187	$358	$528	$699
	+75%	($36)	$136	$307	$477	$648
	+100%	($87)	$85	$256	$426	$597

[1] A base poblano pepper price of $3.68 a peck was determined from the average prices at Fairview Auction from August 16th 2010 to September 7th, 2010.
[2] A base water price of $0.0042452/gal was used that represented city water for Lexington, KY.

Table 9c. Change in net returns per acre for operating an elaborate automatic pulse irrigation system at -50/-45 when compared to a manual irrigation system at a rate of -50/-10 for 2010 poblano pepper production in Kentucky under various water and pepper prices.

		Pepper Price				
		-50%	-25%	Base[1]	+25%	+50%
Water Prices	Base[2]	$556	$978	$1,399	$1,821	$2,242
	+25%	$489	$911	$1,333	$1,754	$2,175
	+50%	$422	$844	$1,266	$1,687	$2,108
	+75%	$355	$777	$1,199	$1,620	$2,041
	+100%	$288	$710	$1,132	$1,553	$1,974

[1] A base poblano pepper price of $3.68 a peck was determined from the average prices at Fairview Auction from August 16th 2010 to September 7th, 2010.
[2] A base water price of $0.0042452/gal was used that represented city water for Lexington, KY.

Table 9d. Change in net returns per acre for operating an elaborate automatic pulse irrigation system at -60/-55 when compared to a manual irrigation system at a rate of -50/-10 for 2010 poblano pepper production in Kentucky under various water and pepper prices.

		Pepper Price				
		-50%	-25%	Base[1]	+25%	+50%
Water	Base[2]	$517	$719	$1,001	$1,284	$1,566
	+25%	$490	$692	$975	$1,257	$1,539
	+50%	$463	$665	$948	$1,230	$1,512
	+75%	$436	$638	$921	$1,203	$1,485
	+100%	$409	$611	$894	$1,176	$1,458

[1] A base poblano pepper price of $3.68 a peck was determined from the average prices at Fairview Auction from August 16th 2010 to September 7th, 2010.
[2] A base water price of $0.0042452/gal was used that represented city water for Lexington, KY.

Comparison of Actual Accomplishments to Proposal Project Goals

The actual project exceeded the proposal objectives by demonstrating two alternative pulse irrigation systems and meet expectations by conducting demonstrations at the primary farm and two cooperators.

Accomplishments – Fruit Demonstration:

The blueberry demonstration sites all demonstrated the effectiveness of the quasi-pulse automated irrigation system and the capability to save water while maintaining or increasing yield.

Blueberries of Daviess County, Utica, KY:

There was no statistically significant difference in blueberry yield, blueberry size and in berry brix or sugar content between the quasi-pulse and manual irrigation systems (Table 10). 2011 yields were 13,624 lbs/ac and 13,233 lbs/ac for the quasi-pulse and manual irrigation systems, respectively.

Table 10: Fruit Yields 2011 & Irrigation – 2010

Farm/Trt.	Yield (lb/A)	Berry Size (oz)	Brix (%)	Irrigation 2010 (gal/A)
Davis Co.				Soil: Clay Loam
Pulsed	13,624 A	1.44 A	10.7 A	57,467
Manual	13,233 A	1.44 A	10.3 A	137,896
Reed				Soil: Clay Loam
Pulsed	2,791 A	1.36 A	12.9 B	109,810
Manual	1,291 B	1.31 A	14.5 A	47,922
Caludi				Soil: Silt Loam
Pulsed	5,104 A	1.62 A	12.0 A	210,345
Manual	5,362 A	1.70 A	11.9 A	139,522

Means within columns followed by the same letter are not significantly different, Waller-Duncan LSD (P>0.05)

There was no statistically significant difference in annual terminal shoot growth between the manual and quasi-pulsed plants (Table 11). Blueberry shoot growth does not seem to be affected by fairly large differences in irrigation amounts applied through the manual or quasi-pulse systems.

Table 11: Blueberry Shoot Growth – 2010

Treatment	Blueberries of Davis Co. 'Darrow' (in)	Reed 'Spartan' (in)	Caludi 'Nelson' & 'Jersey' pooled[1] (in)
Manual	15.9 a	11.9 a	12.8 a
Pulsed	14.8 a	11.9 a	12.6 a

[1]Means within columns followed by the same letter are not significantly different, Waller-Duncan LSD (P>0.05) Means are based on annual shoot growth from 10 terminal shoots per bush from 5 plants.

The quasi-pulse irrigation system water usage was 58.3% and 45.1% less than the manual irrigation system for 2010 and 2011, respectively (Table 12).

Table 12: Quasi-pulse Irrigation System Water Usage for Blueberries of Daviess County

Year	Dates	Quasi-pulse (gallon/acre)	Manual (gallon/acre)	Quasi-pulse Versus Manual (%)	Quasi-pulse versus 1 in/week (%)
2010	6/7 – 10/16	57,467	137,896	58.3 less	60.4 less[1]
2011	6/7 – 10/24	310,845	566,421	45.1 less	50.3 more

1 Example of calculation – 18.7 weeks (6/7 – 10/16) X 4 ft blueberry row width / 14 ft spacing between rows X 27,154 gal/ac-ft. = 145080 gal/ac. (145,080 – 57467)/145,080 = 60.4%

Reed Valley Orchard, Paris, KY:

The blueberry yield in 2011 was 1,500 lbs greater for the quasi-pulse irrigation system compared to the manual irrigation system (Table 10). There was no difference in berry size however an higher brix content was found in the manually irrigated plants in 2011 (Table 10). This would be expected as the yields were substantially lower for the manually irrigated plants and the sugars produced by the plant were concentrated in fewer fruit.

2011 yields were 2,791 lbs/ac and 1,291 lbs/ac for the quasi-pulse and manual irrigation systems, respectively.

An increase in water use of 2.3 times more with the quasi-pulse system then that applied manually was measured at the Reed farm in the 2010 season (Table 13). Water applied in 2010 results in flower set that generates 2011 yield. Thus in 2011 there was a 1,500 lb per acre increase in fruit yield achieved in the quasi-pulse irrigated plants compared to the manual irrigation system.

In 2011, a very wet year, the quasi-pulse irrigation system only used 172 gallons/ac whereas the manual application used 140,000 gallons/ac (Table 13).

Table 13: Quasi-pulse Irrigation System Water Usage for Reed Valley Orchard

Year	Dates	Quasi-pulse (gallon/acre)	Manual (gallon/acre)	Quasi-pulse Versus Manual (%)	Quasi-pulse versus 1 in/week (%)
2010	6/2 – 10/28	109,810	47,922	56.3 more	33.0 less
2011	6/9 – 10/3	172	140,103	99.9 less	99.9 less

Caludi's Fields, Lexington, KY

There was no difference in berry size between the quasi-pulse and manual irrigation systems. There was no difference in berry brix or sugar content at the Caludi's Fields in 2011 (Table 10).

2011 yields were 5,104 lbs/ac and 5,362 lbs/ac for the quasi-pulse and manual irrigation systems, respectively.

Table 14: Quasi-pulse Irrigation System Water usage for Caludi's Fields

Year	**Dates**	**Quasi-pulse (gallon/acre)**	**Manual (gallon/acre)**	**Quasi-pulse Versus Manual (%)**	**Quasi-pulse versus 1 in/week (%)**
2010	7/7 – 10/26	*	*		
2011	6/3 – 9/29	117,365	318,015	63.1 less	10.6 less

Wiring mistake precluded accurate measurement of water in 2010. It was corrected on August 10, 2010.

Water usage by the quasi-pulse irrigation system was 63.1 % less compared to the manual system in 2011 (Table 14).

The last column in Tables 12 – 14 provides a comparison between the quasi-pulse irrigation system and the, "rule of thumb" of applying 1 acre inch of water per week through the summer. Comparisons among these quasi-pulse, manual and 1 in/week methods show that there can be substantial variations between the, "rule of thumb" and what may actually be needed due to variables such as temperature, humidity, plant size, crop load, soil type, soil structure, rooting depth, and if plants are mulched.

Comparison of Actual Accomplishments to Proposal Project Goals

A refined quasi-pulse irrigation system was developed beyond that which was in the proposal. The quasi-pulse system proved much easier to install and operate than that which was in the proposal. Three cooperators were involved in the demonstration versus the two listed in the proposal.

Cost Comparison Between the Quasi-pulse and Manual Irrigation System

<u>Blueberries of Davis County</u>

Based on differences in water use between the quasi-pulse and manual irrigation systems of approximately 80,000 and 256,000 gal/ac and a water cost of $3 per 1,000 gallons there was a cost saving of approximately $240/ac and $770/ac for 2010 and 2011, respectively (Table 12). The quasi-pulse yield was 391 lb/ac greater than that of the manual system and based on a 2011 FSA Kentucky average blueberry price of $4.27/lb, generate an additional revenue of approximately $1,670/ac.

The quasi-pulse irrigation system cost $740 plus perhaps another $100 in miscellaneous expenses and a couple of hours of labor. Assuming that the quasi-pulse irrigation system could be made operational for $1,000 then the entire system could be paid for simply through a single acre of water savings in 2010 and 2011 or by the increase in fruit revenue from a single acre in

2011. Hence, the quasi-pulse irrigation system proved to be quite economical for the Blueberries of Davis County Farm.

Reed Valley Orchard

The quasi-pulse irrigation system in 2010 required 61,888 gallon more water than the manual system. At approximately $3 per 1,000 gallons the additional water used cost approximately $185. The increase in yield of 1,500 lbs, when valued at the 2011 FSA Kentucky average blueberry price of $4.27/lb, generate an additional revenue of approximately $6,400/ac. These results demonstrate that the quasi-pulse irrigation system works very well providing a substantial increase in yield for a minimal increase in water cost.

The increased fruit revenue of $6,400/ac minus increased cost of water of $185/ac could pay for the entire quasi-pulse irrigation system while realizing a profit of greater than $5,000/ac for the Reed Valley Orchard.

Caludi's Fields

At the Caludi farm system wiring problems compromised the data in 2010. However a substantial irrigation savings of $587 was achieved in 2011 by using the quasi-pulse system. The results from the blueberry demonstration sites show that substantial water and dollar savings were achieved and that a quasi-pulse automated irrigation system would be easily justified and paid for with the water savings obtained at all three demonstration farms. The demonstration also showed that irrigation is necessary even in very wet seasons and that the quasi-pulse automated system can supply water at critical times when growers might be distracted by other aspects of their operation. Experience with this system has revealed that a grower cannot turn the system on in the spring and return in the fall to turn it off. Automatic systems still require careful grower monitoring. We experienced water leaks, low water pressure that did not allow the system to switch on, high water pressure that blew emitters out of the lines and mole digging around sensors resulting in abnormal readings. It is also a bit of a challenge to determine if the automated system is running correctly as it does not necessarily operate when the grower is in the field. Future plans are to demonstrate this system using ½ gallon emitters to enable more water pulses over a longer period of time.

The yield for 2011 was higher for the manual irrigation system then the quasi-pulse system by 258 lb/ac. Water difference between the systems is unknown for 2010. Water savings in 2011 was approximately 200,000 gal/ac, which translate into a savings of approximately $600/ac. Combining the loss revenue in fruit production in 2011 of $1,100/ac yields generated a loss of $500/ac. It should be noted that if there were additional water saving in 2010 then there may have been no loss in profit.

Comparison of Actual Accomplishments to Proposal Project Goals

The cost of the three newly developed pulse and quasi-pulse irrigation systems saved approximately 50 % compared to the proposed pulse irrigation system thereby enhancing the economic efficacy of pulse irrigation for producers.

Blueberry demonstration plot results were presented to growers at three Horticultural Research Farm field days/tours, in two years at the Kentucky Fruit and Vegetable Conference and at the Tennessee Fruit and Vegetable Expo. Seminars were also given in the U.K Horticulture and Biosystems and Ag Engineering departments.

Extension Outreach Activities:

Summary of Outreach

- Outreach (technology transfer) programs conducted throughout this project, and continuing to date, were substantially greater than originally proposed in the grant application. Outreach activities included:
    - Three Horticultural Demonstration Field day/tours (attendance ~ 400)
    - Kentucky Fruit and Vegetable conferences (~160)
    - Tennessee Fruit and Vegetable Expo (16)
    - 18 Producer Events (~400)
    - ~ 30 1-on-1 consultations on irrigation management and scheduling based on pulse irrigation lessons learned
    - Modified irrigation designs and expansion to non-traditional drip irrigation applications (representative examples):
        - Doubled tomato production area without replacing the pump or main pipeline through implementation of pulse irrigation strategies
        - 6 ac of mined land energy crop production through automatic irrigation scheduling using a 7.5 kw gas generator
        - 100 ac tobacco irrigation project that decreased the pump size 3-fold and decreased the main irrigation line from 6 inches to 3 inches through incorporation of pulse irrigation-type scheduling.
    - An Extension publication on Tensiometer Installation. Note incorrect tensiometer installation was found to be the major problem with an effective pulse irrigation system due to short circuiting (preferential flow along the side of the tensiometer) causing inaccurate tensiometer moisture readings and feedback to the control system.
    - Two refereed articles.

A large field day was held at the primary demonstration site on July 22, 2010. This project was featured at two locations on the farm (vegetables and fruit) and each location received two tours. Approximately 120 growers and extension personnel attended the field day with roughly 100 visiting the demonstration stops (Figure 20).

Figure 20: Setup for Field Day

Table 16: Regional, State, and County Level Outreach Activities Associated with Pulse Irrigation

Location/Event	Date	Number of Attendees
Lexington, KY; Blackberry pulsed irrigation, Horticultural Research Farm Field Day	September 11, 2009	85
Owingsville, KY; Irrigation for vegetables	December 10,2009	32
Nashville, TN; Pulsed irrigation for vegetables	January 29, 2010	24
Somerset, KY; Improving vegetable irrigation	March 25, 2010	19
Lexington, KY; NRCS thornless blackberry pulsed drip irrigation demonstration, Horticultural Research Farm Twilight Tour	July 22, 2010	100
Lexington, KY; Field day on irrigation	July 22, 2010	100
Lexington, KY; Pulsed and quasi pulsed irrigation of vegetables	January 3, 2011	100
Lexington, KY; Automated pulsed drip irrigation for vegetables and fruit, Kentucky Fruit & Vegetable Conference	January 4, 2011	100
Springfield, IL; Pulsed drip irrigation for vegetables	January 6-7, 2011	45
Crab Orchard, KY; Improved drip irrigation for vegetables	January 11, 2011	56
Indianapolis, IN; Pulsed drip irrigation for vegetables	January 19, 2011	40
Liberty, KY; Irrigation tactics for Mennonite growers	March 1, 2011	24

Murray, KY; Irrigation management for vegetables	March 16, 2011	18
Flemingsburg, KY; Irrigation management for vegetables	April 19, 2011	26
Lexington, KY; On farm hands-on irrigation training	July 5, 2011	8
Lexington, KY; On farm training (including irrigation)	September 5, 2011	22
Lexington, KY; Blueberry automated quasi-pulse irrigation, Kentucky Fruit & Vegetable Conference	January 6, 2012	62
Lexington, KY; Blueberry & blackberry quasi-pulsed irrigation, Donovan Scholars Tour, Horticultural Research Farm	July 10, 2012	13
Lexington, KY; Blueberry automated quasi-pulse irrigation, Horticulture Departmental Seminar	November 16, 2012	35
Lexington, KY; Blueberry automated quasi-pulse irrigation, Biosystems and Ag Engineering Departmental Seminar	November 30, 2012	14
Nashville, TN; Pulsed irrigation for vegetables, Tennessee Horticultural EXPO	January 26, 2013	16

Appendix A: Extension Publications

Coolong, TW. and S. Surendan. 2011. Tensiometer Installation. HortFact 7003.

Appendix B: Journal Articles

Coolong, T.W., S. Surendran, J. Snyder, R. Warner, and J. Strang. 2012. The relationship between soil water potential, environmental factors, and plant moisture status for Poblano pepper (*Capsicum annuum*) grown using tensiometer-scheduled irrigation. International J. Veg. Sci. 18:137-152.

Coolong, T.W**.,** S. Surendran*, and R. Warner. 2011. Evaluation irrigation threshold and duration for tomato grown in a silt loam soil. HortTechnology 21:466-473.