CONSERVATION INNOVATION GRANTS
Final Program Report

Grantee Name: **El Dorado Irrigation District**	
Project Title: **Scheduling irrigation for commercial agricultural growers within the El Dorado Irrigation District using permanently placed soil moisture sensors.**	
Agreement Number: **NRCS 68-3A75-6-181**	
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Executive Summary:

This project has demonstrated that Watermark sensor***** values are directly related to neutron probe measurement values in a site specific manner. However, the results at one site can not be universally applied. Currently, this relationship must be determined in a site specific fashion. This project has allowed this relationship to be determined for over 275 crop monitoring sites through the purchase of Watermark sensors and AM400 data loggers. An installation protocol was developed that greatly reduced the sensor failure rate. Data logger down load protocol was simplified and removed human error potential from the file naming and sorting operations. Changes to the irrigation scheduling software have been made to incorporate this sensor technology and allow its use in irrigation scheduling. A web-based grower portal has been developed so that growers can enter the sensor information to update irrigation schedules as needed. This project has demonstrated that this technology can meet all of the project deliverables as outlined in the project proposal. Finally, this technology can be transferred to nearly all growing regions.

** The names of the products and manufacturers provided herein are strictly for informational purposes only. Neither the National Resource Conservation Service nor the El Dorado Irrigation District in any way endorses these products or manufactures.*

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1. Project Summary:
1a. Purpose; the purpose of this project was to purchase soil moisture sensors and data loggers. The equipment is being tested to determine if a neutron probe can be replaced with permanently placed sensors to increase irrigation scheduling capabilities and efficiencies.

1b. Natural resource concern(s)/technology addressed; the project was designed to address the Natural Resource Concerns; Water Resources; Irrigation management for water conservation. The project focused on improving irrigation scheduling and management techniques to increase water conservation and efficiency.

1c. List of deliverables included;

- Increased irrigation efficiency
- Increased water conservation
- Increased crop quality
- Improved soil quality
- Decreased run off
- Decreased erosion

2. El Dorado Irrigation District's Irrigation Management Service (IMS) Program:
2a. Program development; a two-year drought started in 1976. One-half of Jenkinson Lake was utilized during that first year. At that time Jenkinson Lake was a United States Bureau of Reclamation (USBR) project and supplied the majority of the El Dorado Irrigation District (EID) agricultural irrigation water. The Bureau required an agricultural water conservation program to be developed due to the rate of water consumption by agricultural customers.

In 1978 a three-year grant was obtained by Dr. Richard Bethel, El Dorado County Cooperative Extension director, to study ways to conserve water in an agricultural setting within EID. This study had many collaborators that included representatives from the federal, state, county, and local governments, EID, and private individuals. The results of the study were published in June, 1981 in a report titled "*Irrigation Management for the Sierra Nevada Foothills of California*."

The results of this study demonstrated that the best way conserve agricultural water was to use weather-based irrigation scheduling, monitor soil moisture status with a neutron probe, and determine sprinkler system discharge rates and efficiencies. This would provide the grower with the information as to when to irrigate and how long to run a particular irrigation system to only replace the depleted soil moisture. A number of growers noticed that seeps and "springs" disappeared after the program was initiated which strongly suggests that tail water and run-off were eliminated by this program.

2b. Documented water savings by IMS; in 1986 the Department of Water Resources (DWR) requested a water-savings audit for the IMS program. EID staff examined the water consumptive histories for growers participating in the program. The staff focused on two similar weather-years where one was prior to the program initiation and one after the program start. The audit found that the participating growers irrigating ~2,500 acres were conserving 2,424 acre-feet (af) per year by following the IMS irrigation scheduling recommendations. The results were accepted by DWR, and this was the first documented agricultural water savings in California.

Prior to the program most growers were irrigating with portable irrigation pipe which required 10 days to complete one irrigation cycle. At that point the grower would return the pipes to the first row and start the process over. The result was that growers were irrigating continuously from the middle of May to the middle of September. Weather-based irrigation scheduling and monitoring soil moisture status allowed the growers to eliminate 2 irrigation events per season. The sprinkler efficiency results found that growers were discharging approximately 6" of water per event at 48% efficiency. Through outreach the growers decreased the discharge to 4" per event and increased efficiency to over 80%.

2c. Current IMS program; The Irrigation Management Service (IMS) program is free to Agricultural-Metered Irrigation (AMI) customers. AMI is defined as 5 or more acres in production which is a definition used by USBR. The current program has 100 customers irrigating 2,500 acres. This accounts for approximately 70% of the commercial irrigated acres within EID. There are 310 sites that are monitored once a week with a neutron probe during the irrigation season. This requires 35 hours per week to visit all of the sites, record data, verify the collected data, and issue reports to the growers.

2d. IMS main components; the four main components of the IMS program are an **ET-capable weather station, a neutron probe, predictive irrigation scheduling software**, and **webpage access.**

- The first component, an evapotranspiration (ET)-capable weather station, was installed on October 19, 1982 within the District. The station has been in continuous operation since. The weather information allows the IMS program to calculate daily ET averages over a 25 year history. This average, used to calculate the future water needs of the various commodities, is the backbone for the IMS program. This station is part of the DWR California Irrigation Management Information System (CIMIS).

- The second component of the IMS program is the neutron probe. Neutron probes are the standard by which other monitoring equipment is measured. Nearly all of the published crop coefficients and crop curves have been determined with the neutron probe. The neutron probe uses a radioactive source to generate high energy neutrons to measure soil moisture levels. To possess a neutron probe in California requires a radioactive permit issued by the Department of Human Services. Currently this permit costs $1,400 per year plus elaborate security to protect the device. The neutron probe does not need direct soil contact to measure soil moistures. Therefore, permanent access tubes are installed at monitoring sites. The neutron probe is composed of two units attached by an 8' cord. The controller/display unit is rather large and sits on top of the access tube. The source/detector is lowered down the middle of the controller unit into the access tube down to the depths being measured. The probe measures a soil volume approximately 12" in diameter. This requires that the shallowest depth to be measured is 9". Any closer to the soil surface allows some of the neutrons to escape which cause errors in the measurement. Therefore the device is not practical for shallow rooted crops such as blueberries. Further, the device only provides a snapshot of soil conditions at the time the device is used. Elaborate crop models must be used to predict crop water needs between measuring events.

- The third component is the predictive irrigation scheduling software. EID uses state-of-the-art software (TrueISM by TruePoint Solutions) that was specifically developed for the IMS program. The software was developed in less than three months and went live on June 1, 2005. This software is browser-based and resides on one of the EID servers. Currently, EID has unlimited access to this software meaning that all employees could access this software at the same time if conditions require it. There are two main sub-components to the current software package. The first is the day-to-day operations where a majority of the operations are automated included weather data downloads and grower report delivery by email. The second component is the field application where all of the data logger information and neutron probe readings are recorded on a tablet computer. At the end of the day this tablet is connected to the network and the prediction database updated. The software then re-calculates all of the irrigation predictions automatically based on the most recent data.

- The fourth component is a grower portal where growers can access their site specific information any time they require across the internet. This portal went live on September 1, 2008. Historically, the growers received a report once a week that contains static information. The current software re-calculates irrigation predictions as new information becomes available including the daily weather information. The portal will allow growers to check on irrigation predictions as weather conditions change between site visits.

2e. IMS problem; the major problem of the IMS program is that the neutron probe provides a snap-shot of soil moisture conditions at the time the equipment is used. Elaborate crop curves must be used to predict water consumption at all other times. Plus, if this single piece of equipment breaks or malfunctions then all of the participants are impacted. Finally, due to 9/11 and the current financial crisis the requirements and costs of using a neutron probe is becoming prohibitive. Finding a replacement for this device has become a priority for the program.

3. Rational for the NRCS-funded study:

IMS has over 25 years of neutron probe measurements from 300 sites. These sites are scattered across the District from Cameron Park to Pollock Pines which represents an elevation change of over 2,500 feet. Due to this topography within the District the IMS program has sites which are grown on over 40 soil types as described in the 1974 soil survey report published by the Soil Conservation Service. As a result the water needs of a single commodity vary by over 2.5 af based on elevation, aspect, and cover crop management choices. This has resulted in the development of over 40 crops curve to predict the water needs of all of the commodities grown within the District.

An example of the complexities found within the District is found on one ranch that is growing 7 wine grape varietals on 7 acres. The growing area is divided into two regions of 1 acre and 6 acres that are separated by approximately 100 meters. Even in this small area the farmer is producing premium wine grapes on 4 different soil types. The soil on the eastern edge is Rescue clay, clayey variant (Rk), containing ~55% clay, and has a soil moisture content of 17.70" over 4'. The soil on the western edge is Rescue very stony sandy loam (RfC), containing <5% clay, and has 11.65" of soil moisture. This requires the grower to have different irrigation schedules for each variety due to the change in soil conditions.

The big draw back to all of the soil moisture sensors currently on the market is that they all use scales that can not be applied to published crop curves generated by the neutron probe, so they can not be used for irrigation scheduling. The sensor scales are either time to propagate a signal or the amount of electrical resistance. Both must be converted to a scale that represents the amount of water in the soil. Since both types require direct soil contact, the type of soil the sensor is placed in will also change the meaning of the scale values.

This suggested that the IMS program could be the ideal test environment to compare sensors and neutron probes due to all of the monitoring sites located in a number of soil conditions. The premise of this project was to place a specific sensor near the neutron probe access tube to determine if calibration curves could be developed that would convert the sensor reading to a neutron probe equivalent. This would allow the historic crop curves and coefficients to be maintained while modifying the IMS program to allow for new soil monitoring techniques. Currently, sensors only tells a grower if it is time to irrigate, not when to irrigate. Results from the project will allow sensors to be used in irrigation scheduling.

4. Sensor and data logger selection:
A number of soil moisture sensors and data loggers were examined to determine the most effective theoretical combination for the IMS program. The main considerations were the cost, reliability, and user friendliness. Initial comparison showed that sensors varied from $25 to over $1,000 dollar while the logger varied from $250 to over $1,500. Many of the sensors have been developed fairly recently and have limited field testing history, so they were eliminated. This left sensors that fell into two categories of either electrical resistance or time required to send a signal down a closed loop. Both of these measurements change as the amount of water in the soils change. In addition, both types require direct soil contact to function. Ultimately it was decided to purchase the Watermark sensor supplied by Irrometer which uses electrical resistance as a soil moisture measure.

Irrometer has developed both the tensiometer and Watermark sensor. Tensiometers were one of the first soil moisture monitoring devices uses by the IMS program in the late 1970's. Simply, the tensiometer is a vacuum gauge that measures how much force the plant must use to extract moisture from the soil. The scale used on this device is measured in centibars (cb) where 100 cb is equal to one atmosphere (14.7 pounds per scale inch) of vacuum pressure. Most irrigation events occur when the tensiometer reaches a value of 70 cb. Irrometer uses this same scale for the Watermark sensors. Since tensiometers were used by the IMS participants they felt comfortable using this scale to schedule irrigation events.

Most monitoring sites required 3-4 sensors. This resulted in a final purchase of 1,200 sensors to meet the needs of this project. Irrometer allowed EID to buy them in bulk at a cost of $24.62 per sensor due to the large number of sensors required for this project. Irrometer is currently charging approximately $32 per sensor.

A number of data loggers were examined to determine the most appropriate for this program. The AM400 manufactured by MK Hansen was the device chosen. The AM400 has one unique feature that made it stand out from other loggers. This feature is a built-in numeric and graphical display that allows the user to view soil moisture conditions while in the field. The display is configured so that the user can use one button to step through all of the sensor values. Further, the display can be configured to display the sensor average of all the sensors that the grower deems appropriate. This display also has a variable scale depending on the largest resistance measured a particular sensor. The possible display ranges are 0 to 25, 50, 100, or 200 cb depending on the soil and crop being monitored. Further, the last recorded value is also displayed so the grower knows exactly what the conditions are surrounding the sensor while he is at the site. This display function gives the grower a great deal of power and comfort about the trends and stress levels at his particular site. Other feature include; 1) runs on two AA batteries, 2) logs data for up to six sensors, 3) variable rate for data recording, 4) one button use, 5) sensors are automatically temperature corrected, 6) sensors can be located up to 1,000 feet away, and 7) installation requires no special tools or training. The data logger comes with a soil temperature sensor (thermistor) that is installed at the 2'-depth which provides a temperature calibration for the sensors.

After negotiation with MK Hansen, a final price of $286 for the data logger and $17.25 for the thermistor was adopted.

5. Sensor and data logger installation:

The IMS program has found that the most appropriate place for the monitoring site is dependent on the irrigation system at that site. If sprinklers are used then the site is placed equidistant from 3-4 sprinklers depending on the sprinkler arrange and approximately 2/3 of the distance from the trunk to the drip line. The site is always placed in the vine or tree row to reduce or eliminate impact to the grower and equipment. For drip systems the site is placed within 1' of the emitter. When placing sensors at a drip system site, the 1'- and 2'-sensors were placed on the side of the access tube closest to the emitter. This is to ensure that the sensors are in the irrigation water cone as the water infiltrates the soil.

A 2"-soil auger was used to drill holes down to within 2" of the neutron probe measuring depth. The edge of this hole closest to the access tube was less than 6" from the middle of the tube. A 7/8" steel rod was then driven into the soil 2" to provide an access hole for the sensor. The wires for the sensor was then run down the middle of a 5'-, 3/4"-schedule 40 PVC tubing that was marked at 1' intervals through four feet. The rim of the sensor just sits within this tubing. The sensor is then seated into the pilot hole using the PVC tubing. The tubing is gently tapped until the appropriate mark on the tube is at ground level so that the sensor firmly sets in the pilot hole. The tubing is then removed. The wire is gently tugged to confirm that the sensor is securely set. The last 6" of soil extracted from the hole is mixed in a small bucket with water to a wet cement consistency. (If the soil is fairly sandy then fines are added to the mix to increase sensor contact. Heavy clay soil may need to be pulverized before the water is added to increase sensor contact.) This mixture is then poured down the hole. The hole is then back-filled with gentle tamping every 4 to 6" and additional water, if needed, to ensure a good seat. In this fashion, the sensors are placed around the access tube.

The decision was made to place one sensor per hole instead of placing all of the sensors in one hole. The rational was that the sensors are mechanical devices that will ultimately fail. (Some Watermark sensors have been in the ground for over 15 years without failing.) It would cause a problem if you have to disturb the top three sensors to replace the bottom sensor. In the arrangement for this project only the bad sensor needs to be disturbed thus retaining the soil contact present at all of the other sensors. The sensors are placed at 1', 2', and 3' for the tree crops. An additional sensor is placed at 4' for grapes. The thermistor is installed at the 2' depth.

After all of the appropriate sensors are installed, a number of loose wires were scattered around the access tube. The wires were then run in a ¾"-PVC tube matrix to protect the wires from the elements and critters. The tubing stopped just below the soil surface so as not to direct any moisture artificially towards the sensor. The joints were not glued to allow for disassembly in case sensors have to be replaced. In a few cases this matrix is buried to a depth of 6" to allow the grower close access to the monitoring site. The tubing was then run 12-18" from the access tube to base of an installed grape stake. This stake had been driven into the ground 12-18". The tubing containing the wires was run up the stack 18-36" and the data logger placed on top of the tubing.

The AM400 has a ¾"-hole at the bottom of the device. This hole was increased to 1" using a twist bit. This allowed a ¾" threaded male PVC fitting to be installed. This produced a water- and insect-tight fit when the logger was installed on the tubing containing the wires. A L90 Simpson Strong Tie brace was modified by drilling three holes into the metal (see Figure 1). The brace was attached to the back of the logger using two, ½" #8 pan head metal screws. The brace was then secured to the grape stake using a u-bolt specifically designed for vineyard operations. The PVC tubing was secured to the grape stake in two places using 11" cable-ties with the excess being clipped off. The u-bolt and grape stake were purchased from a local vineyard supply house.

A color code was developed to eliminate confusion when connecting the sensor wires to the logger. A five-color electrical tape dispenser, as well as the Simpson Strong Tie, was purchased from the local home improvement store. The 1'-, 2'- , 3'- and 4'-sensors were labeled with red, blue, green, and yellow tape respectively. The thermistor was labeled with white tape. The sensor ports on the AM400 are labeled S1-S9. S7 and S8 are restricted to the thermistor while S1-S6 ports are reserved for the sensors. The 1'-red taped sensor was connected to the S1 port. The depth in the soil profile was made equal to the S value when measured in feet. The thermistor is always connects to the S7 port due to the fact that the blank S8 port is used for internal calibration by the logger.

After all of the wiring was completed then two AA batteries were installed. The time and date of the battery installation recorded. (The AM400 does not have a time or date stamp so this information is entered into the prediction software to establish a time frame for the collected data.) The data logger was then programmed using Hyper Terminal communication software (part of the Windows operating system) and a comma delimited ASCII format file. This file programs the data logger as to the time interval for data collection, which sensors are used in a calculated averages and the threshold values seen on the display. The sampling time was set to every 4 hours for all of the loggers. The thresholds and sensor averages varied depending on commodity and location. The prediction software engineer work with the MK Hansen to change this primary programming file to include a 4-digit unique identifier. This removes human error for correctly labeling data files in the field.

The time required to install sensors and a data logger varied depending on the soil type at a particular site. The range was from 1.5 to 4 hours with the average being approximately 2.5 hours. The final installation configuration can be seen in Figure 2. The cost for just the sensors, thermistor, data logger, and support was ~$400 per site. Total varied depending on the time required to install all of the components.

6. Data logger information down load:
Data logger file recovery was simplified for this project through the use of the prediction software. The normal AM400 file recovery requires multiple steps and user input to appropriately label files. Once the file is recovered then different software must be used to graphically display this information. An external time stamp must be applied to this data file to view the soil moisture trends. Small errors in this external stamp may not be a problem for permanent crops, but could be catastrophic for row crops.

Data recovery was greatly simplified for the IMS program through the predictive software and field application being used. The field software application is opened on the field computer and the appropriate site inspection accessed. (If the wrong site is accessed the software will open the appropriate site based on the unique identifier received from the data logger.) The serial cable is connected to the computer and inserted into the female connection located at the bottom left-hand corner of the logger. The weather cover is removed from the data logger. This exposes the display and access button. This button is then pressed twice to start the down load process. The first press wakes up the data logger while the second starts the file download. At this point a dialog box opens on the field computer that shows a timing bar and the statement “Downloading data logger #XXXX.” After the download is complete another box opens that displays the collected tabular data and allows the operator to either discard or save the data. Once the data is saved the data is no longer accessible by the field application. (Final quality analysis of the data is done in the office by the main operating software once the data is uploaded to the database.) While the data is being downloaded and saved, the operator can collect and enter the neutron probe measurements. Over 80 data loggers down loads and associated neutron probe measurements were completed in one typical day using this protocol

7. Data analysis:
The principles behind using the neutron probe are fairly simple, but the value obtained and how it is used must be explained to understand the data analysis. The device used by EID is configured so that the counted neutrons are displayed as inches of water per foot (in/ft). Neutron probe measurements are taken at the start of the season when the soil is saturated with water, and this is called the field capacity. (The difference in the field capacity for all of the sites in the IMS program can range from 2.5 to 5.00 in/ft depending on the soil type.) During the irrigation season the sites are measured once a week. This measured value is then subtracted from the field

capacity to determine the amount of depleted water. When the amount of depleted water reaches the Managed Allowable Depletion (MAD), then it is time to irrigate. The MAD is dependent on the crop and the monitored root zones with most MADs ranging from 1.5" to 4.0". The MAD is the depleted soil moisture totaled over 3' for tree crops and 4' for grapes just prior to plant stress.

Data analysis was started by entering the sensor values and neutron probe measurements into an Excel spreadsheet. The last sensor value recorded was the value used in the analysis. Initially, the values were compared on a per foot basis and no relationship was seen. The sensor average and depletion average were then calculated and compared. This comparison produced a linear average at most sites. The average was calculated by summing the values then dividing by the number of feet in the root zone. An example of the data analysis can be seen Figure 4.

Various Excel spreadsheet options were used to analyze the data in a site specific fashion. First, the data was graphed in a xy-scatter plot using the neutron probe depletion average (in/ft) as the y-value and the sensor average (cb/ft) as the x-value. The points in the scatter-plot were compared by adding a best-fit linear trend line. Linear regression function was used to calculate the relative positions of the data points to this trend line. The graphs were displayed with the linear equation ($y = mx + b$, where m is the slope and b is the y-intercept) for the trend line and the linear regression value (R^2-value) of this line (see Figure 5). The points were considered linearly related when the R^2-value was equal to or greater than 0.6. The R^2-value is a measure of how far the points are from the best fit line. The number ranges from 0.0 where there is no relationship to 1.0 where all of the numbers are on the line. Therefore the closer this value is to 1.0 the better the relationship between the plotted values.

8. Results:

Greater than 97% of the sites were found to have R^2-values greater than 0.6 (See Appendix A). This strongly suggests that the Watermark sensor values and the neutron probe values are related over a wide range of growing conditions.

The sites that had values below this threshold level are usually the result of equipment failures or changes in management practices. One site had a bad data logger circuit board that had to be replaced. Three sites had sensors that failed over time, and these will be replaced in the near future. One site had the data logger installed just at the first irrigation event. This site was maintained in a deficit soil moisture condition for the remainder of the year to increase the quality of the harvested commodity. The data produced was scatted over a very narrow range so it displayed a random sample without any discernable pattern. The last three sites had no readily apparent reason for the low R^2-values.

A closer look at the data showed a remarkable feature. The slopes for the linear equation ranged over a 75-fold value (0.0006 to 0.0453). An example of this variability can be seen in the Figure 6 that compares three tree crop sites with identical MAD's as determined by the neutron probe.

One interpretation of the results is that there a decrease in sensor sensitivity to soil moisture conditions as the slope of the relationship increases. This interpretation is based on how the neutron probe and sensor functions in the soil environment and measures soil moisture levels. The probe does not require soil contact and is measuring the amount of water in a given volume regardless of soil type. The sensor on the other hand requires direct soil contact and is only measuring the amount of water in direct contact with the electrodes. Previous work with the soil triangle has demonstrated that water tension changes as the soil type changes (Saxton, K.E. and W.J. Rawls. 2006. *Soil Sci Soc. Am. J.* 70:1569-1578, "Soil water characteristic estimates by texture and organic matter for hydrologic solutions." The soil triangle and graphical representation of water holding capacities can be found in Figures 7 and 8 respectively.)

Comparing the apple site to the plum site demonstrates this interpretation. The crops have the same irrigation start point as determined by the neutron probe. The plum site sees approximately 10 cb change in sensor average versus a 0.2" change measured by the neutron probe. The apple site, on the other hand, shows a 40 cb change in the sensor average over the same 0.2" depletion. Apparently, the sensors are four times more sensitive to soil moisture changes at the apple site than they are at the plum site. The result is that the irrigation initiation thresholds can not be generalized for the sensor information as suggested by the manufacturer. These must be determined in a site specific fashion if they are to be used in an irrigation scheduling program.

Field observations suggest that the results in Figure 6 might be explained by soil types as defined by the soil triangle. The plum site is in fairly clay poor soils and the apple site is in a clay rich soil type. The peach site is some where between these two sites. It appears that a combination of the soil/sensor contact and the percentage of soil water in a particular soil type will determine the sensitive of the sensors to changes in soil moisture.

9. Transferability:

I believe that this technique and technology is transferable to nearly all agricultural production areas. The components that need to be in place are knowledge of the soil type at the growing site, the general irrigation requirements for a crop at this site, and a means to determine irrigation scheduling crop model thresholds.

EID commercial crops are grown on over 40 soil types as describe by the soil survey. This means that one irrigation block can be growing on multiple soil types. The way the IMS program has addressed this issue is to work closely with the various growers. I will walk the field with the grower or look at a map to determine the region that is most prone to water stress. This is where I will ultimately place the monitoring site. Plants do better with a little extra water, but can shut down completely when water stressed. Therefore, the program has found that it is better to schedule irrigations based on the area prone to the most water stress. ***Local knowledge by the grower is critical for this site monitoring placement and success of the program***. A**ll** irrigation scheduling programs are doomed to failure without involving the grower in the process.

The various local, state, and federal agencies have a wealth of information concerning particular crop water requirements. This includes the effective root zone, crop curves, crop coefficients, and historical weather information to calculate daily ET values. This information provides the basis of an irrigation scheduling program that can help growers address multiple resource concerns.

Developing crop irrigation thresholds may be the most problematic for transferring this technology. EID has used the neutron probe to establish these thresholds in a site specifically. This was due to of environmental conditions that forced EID into an agricultural water conservation program. (Since the initial implementation of this program EID has been very proactive in increasing the services available through this program.) Neutron probes are fairly expensive and require a federal license to use, so they might not be appropriate for individuals or small groups growers. There are other techniques that could develop this sensor/site relationship. They may include, but not limited to, lysimeters, thermal imagining, and remote sensing. Nearly any appropriate technique can be used that will relate the sensor reading(s) to the soil moisture and/or plant moisture levels. Applying this over time and measured weather information can generate the relationships needed to implement an irrigation scheduling program based on sensor readings.

With these caveats, I believe that this technique can be widely used to address many resource issues. The data logger and sensors can be configured to function in a number of environments and conditions. Irrometer has developed the technique where these sensors are spot-glued to the end of PVC tubing. This allows sensors to be temporarily or permanently installed. The temporary arrangement is extremely practical for seasonal and/or mechanically harvested crops. The only concern is that the sensor requires 24 hours to equilibrate to a particular area. Further, the sensor need not be wired to a logger function. The grower can purchase a hand-held device that can be used to read the sensors as required. This device is ~$200 and runs off a 9-volt battery. Also, the data logger can be up to 1,000’ from the sensor placement. This allows the grower to place the logger at the end of a crop row to minimize the impact to the growing area. (Most growers actually place these at vehicle window height so they do not need to exit the vehicle to view the information.) As water becomes a more valued resource I believe this technique and technology will find greater use.

10. Problems and Solutions:

10a. Data logger time frame; the main obstacle with the AM400 data down load is that an external time reference must be applied to the collected data. This can cause errors for irrigation scheduling. I am aware of four solutions that can be applied to this case.

- First, do not down load the data; just examine the display screen on the logger. The most recently collected data is always on the right-hand side of the graph. The grower can see trends over the recent past and this is usually enough to know when it is time to irrigate based on a pre-determined sensor value. This does not allow for irrigation scheduling or tending over time, but it can be effective in most cases.

- Second, purchase or develop software that will place a time stamp on the recovered data. This is the solution used by the IMS program. It is critical that the day and time the logger is first activated is recorded. This establishes the external stamp that is used to analyze the trends to predict the next irrigation event.

- Third, Dr. Clinton Shock (Superintendent, Malheur Experiment Station, Ontario, Oregon) has developed a simple Excel equation to time-stamp imported data. This has yet to be made public.

- Fourth, work with MK Hansen to include a time stamp in the primary coding for the device. This project was able to work with the manufacturer to change the main code to allow for a unique identifier. The prediction software engineer has programmed a number of devices in the past that uses the same language as the data logger. He was able to direct the manufacture down the most appropriate avenue to facilitate this first change. Adding a time stamp would require greater modification, but may be possible in the future.

10b. Data logger delivery; MK Hansen is a fairly small company based out of a residence in Washington. The rate of construction and delivery was approximately ten loggers a week. For small operation this may not be a problem. If large orders are being placed then a long lead time prior to installation may be required. Once again, this company was very easy to work with so this may not be a problem for most situations. This project solved this problem by taking the thermistors as a separate delivery prior to the data loggers. I could install all of the sensors, PVC matrix, and grape stake, then install and program the logger at a later date. I could install up to 8 sensors arrays in a single day, then install up to 10 loggers a day as they arrived. By doing this I still had the sensors in place and could read the values with a hand-held device prior to the data logger arrival.

10c. Serial cable connection; the main weak point in the whole data down load process is the physical connect between the logger and the field computer. This includes the serial connections on the data logger and computer plus the serial cable itself. The connecting cable is made by taking a 6'-stereo cable with 2.5 mm male plugs at each end and cutting it in half. A 9-pin female stereo jack is then soldered to the cut end. The problem is that the cable is either 18 or 20 gauge wire so it does not survive a great deal of physical manipulation. If it is connecting a speaker to a receiver and touched only once it works very well for a long period of time. When it is being connected and disconnected up to 80 times-a-day the cable tends to fail frequently. Further, I tend to keep the cable connected to the field computer for the course of the day. Moving the computer between the vehicle cradle and the data logger also stressed the cable. The IMS program has come up with three solutions to this problem.

- The first solution was to build and maintain 10 serial cables. Five were carried in the field vehicle at all times so replacements were always on hand as needed. Broken cables were replaced with good cables from storage at the end of the day and the broken cables repaired and placed into storage. In addition, extra female connections are carried so that faulty connections in the data logger can be replaced.

- The second solution is to reduce the number of data down loads. This project was trying to generate as much information as possible to increase the accuracy of the data. It has been demonstrated to the IMS coordinator's satisfaction that Watermark sensors can replace the neutron probe as the main soil moisture monitoring equipment. Now the program has developed the protocol so that the data is only down loaded once a month. A new dialog box on the field application has been developed so that the field staff can enter the sensor values without downloading the data. This box will also be accessible to the grower through the grower portal so they can enter data at any time to update irrigation schedule. This entered data will be placed in a temporary file that will be over written once the logger is down loaded. This will greatly reduce the number of down loads thereby decreasing the rate of cable failure.

- The third solution would be to somehow develop a wireless communication arrangement so that this physical connection is no longer an issue. This solution may not be possible at the present for the AM400 but it is still nice to consider all options.

An additional communication problem developed late in the 2008 irrigation season. One of the pins on the computer serial connection broke during a down load. This serial connection is soldered directly to the computer motherboard so a field repair was not possible. The tablet was still under warranty so I was able to obtain a loaner from the manufacturer (MobileDemand) during the repair process. The hard drive was moved between the computers so that the loaner did not have to be imaged prior to use. Repairs were completed in less than 3 weeks which includes ground transport to and from the manufacturer (approximately 7 days for each direction).

10d. Sensor failure; sensors are manufactured mechanical devices that will ultimately fail. Some of the devices slip through the quality control program and are defective at the time of delivery. Solution to this is to test the sensors prior to installations. The sensors are normally soaked in water prior to placement to ease equilibration in the soil. It is possible to use the hand-held device to monitor the sensor prior to soaking and after soaking. The sensor should read 0 cb after soaking. Any sensor reading a number greater than this should not be used.

Sensor failure after installation is a more problematic issue, but the sensor value may help with diagnosing the problem or perceived problem prior to replacement. The two values are always ≤10 cb or always 199cb. Possible causes and solutions are found in the following table.

Condition	Possible Cause	Potential Solution
Sensor always ≤10 cb	*This reading is caused by reduced or no resistance between the sensor electrodes.*	
	Sensor installed below the root zone.	No water loss due to the crop. Determine the appropriate depth for sensor installation from published reports and re-install.
	Ground water near the root zone.	Dig a test pit to see if ground water is an issue. Do not install sensors at depths affected by capillary rise.
	Sensor matrix cracked during installation.	Replace the sensor.
	Salinity in either the irrigation water and/or soil	Test the water and soil for conductivity. May need to use another monitoring technology than electrical resistance for this condition.
Sensor always 199 cb	*This is the maximum reading for the sensor. This indicates a condition of maximum resistance between the sensor electrodes. This is a harder condition to diagnosis*	

	Severed wire during installation.	Replace the sensor. This can be diagnosed by checking the sensor value immediately after installation. The value should be less than 10 cb.
	Wire insulation nicked during the installation.	Replace the sensor. This may happen suddenly or slowly over time as the wire is oxidized.
	Lose of soil contact.	Replace or re-install the sensor. In heavy clay soils the soil will shrink and pull away from the sensor as it dries. This creates and air pocket around the sensor. Add fines during the replacement installation to reduce or eliminate the affect.
	Appropriate value during the irrigation season	No solution required.

The final cause in the table above (always 199 cb) may be an appropriate value for certain soil types to reach during the irrigation season. A few site in the IMS program must reach this sensor average over 3' prior to starting an irrigation event. This usually occurs in heavy clay soils for low water requiring crops such as Christmas trees. Usually this value is reached at the low portion of the root zone. This area is hard to replace water once it is depleted by the crop. Information supplied by Irrometer suggests that clay soils will be extremely dry with sensors values above 140 cb. Project result analysis shows that sensor average about 200 cb is appropriate for some of the monitoring sites. I will work with Irrometer and MK Hansen to determine how best to address this issue.

11. List of deliverables included;

11a. Increased irrigation efficiency; the growers in the IMS program are accustomed to irrigating to just replace the depleted soil moisture. However, these physical systems do wear and discharge rates changes with time. Due to the large number of systems it is impossible to calculate discharge rates and efficiencies on a yearly basis. One grower on the program has solved this problem by using the data logger and sensor information. This grower has irrigation system run-times that are approximately 48 hours. He starts looking at the data logger 24 hrs after he starts the irrigation system and checks at 6 hr intervals thereafter. He turns the system off when the 1'-sensor drops below 10 cb. This usually occurs sometime between 40-45 hrs into the irrigation. This grower is not only using the sensors to tell him when to irrigate, but also when to stop the irrigation. This is increasing his efficiency.

11b. Increased water conservation; the IMS program has previously documented water savings with the introduction of weather-based irrigation scheduling. Growers have received static information once a week on which to base irrigation events. Introducing permanently placed sensors that records and displays soil moisture conditions gives the grower nearly continuous soil moisture status and trending over time. This allows the growers to make irrigation decisions based on the latest available data instead of static weekly information. Further, a grower portal update allows the grower to enter sensor values for a specific site. The prediction software then updates the irrigation schedule based on this latest information.

11c. Increased crop quality; deficit irrigation techniques to improve crop quality are becoming more prevalent through the use of the data loggers. A few of the commodities grown within EID are extremely sensitive to water stress yet deficit irrigation can improve crop quality thereby market price. For these crops it is extremely important to closely monitor the soil moisture status. The sensors and data loggers are allowing these growers to make irrigation decisions on a nearly continuous data trending instead of predictions based on historic weather averages.

11d. Improved soil quality; soils are complex systems where any alterations of the individual properties impacts the whole ecosystem. The soil sensor technology will minimize the impacts to this valuable complex. Timely and accurate delivery of irrigation does reduce run off and erosion thereby eliminating sediment movement. Further, most of the growers in the IMS program have eliminated tilling as a management practice and replaced this with cover cropping as an alternative. Cover crops do increase the amount of irrigation water by approximately 30% in typical settings. But this increased water does improve the soil complex overall health. Further, timely irrigation based on measured parameters does not apply undo stress to this complex from either water saturated or water stressed situation. This sensor technology will be another tool the grower can use to improve soil quality. Better monitoring of soil conditions using the data loggers which are placed at the ends of rows reduces machine traffic within the rows.

11e. Decreased run off; there is anecdotal evidence from a number of growers that "springs and seeps" disappeared after the implementation of the IMS. This strongly suggests that weather-based irrigation scheduling decreased and/or eliminates run off. Also deep percolation seems to be reduced. The IMS program is configured so that irrigation water is scheduled to just replace the amount of depleted water based on a site specific irrigation configuration. The irrigation system has physical components that wear over time so discharge rates will increase. As discussed in 11a, some growers are using the sensor technology to turn systems off after the soil is refilled as defined by the 1'-sensor. This technology will place a greater responsibility for sprinkler efficiency on measured parameters instead of system maintenance. This will further reduce or eliminate run off.

11f. Decreased erosion; the majority of the irrigations systems are designed so that the discharge rate is below the infiltration rate. Irrigations are timed to just refill the soil profile. The result of this combination is that there is little to no pooling of irrigation water on the surface and the soil never exceeds 100% saturation. The irrigation water spends very little time on the soil surface, so there is little to no soil erosion. It may be possible through this sensor technology to reduce the refill point to 90 or 95% of field capacity. This will reduce the amount of potential water pooling on the soil surface and eliminate erosion due to irrigation all together.

12. Provide the following in accordance with the Environmental Quality Incentives Program (EQIP) and CIG grant agreement provisions:

- **1.** *A list of EQIP-eligible producers involved in the project, identified by name and social security number or taxpayer identification number.* A list of the participating growers can be found in Appendix B. No money has been paid to the participating growers so social security and/or taxpayer identification numbers have not been included.

- **2.** *The dollar amount of any direct or indirect payment made to each individual producer or entity for any structural, vegetative, or management practices. Both biannual and cumulative payment amounts must be submitted.* No money has been paid to any of the participating growers for the duration of the project. All of the funds purchased equipment that will be owned and managed by EID.

- **3.** *A self-certification statement indicating that each individual or entity receiving a direct or indirect payment for any structural, vegetative, or management practice through this grant is in compliance with the adjusted gross income (AGI) and highly-erodible lands and wetlands conservation (HEL/WC) compliance provisions of the Farm Bill.* None of the participating growers have received direct or indirect payments for any structural, vegetative, or management practices through this grant.

13. Financial Summary:
This table summarizes the proposed budget and the final status at the end of the project.

Funding Agency	Proposed Budget	Final Budget	Difference
NRCS	$112,845	$112,845	00
EID	$144,602	$142,390	-$2,212
Total	$257,448	$255,236	-$2,212

14. Future research potential:
This project has demonstrated the potential to utilize soil moisture sensors as an irrigation scheduling and resource management tool. A few potential projects suggest themselves from the results of this project. The first is to do texture analysis of all monitoring sites. This would allow an empirical comparison for the neutron probe/sensor/soil triangle relationship. The results may allow a slope-value to be developed for each soil triangle sub-region. A grower would use this value as a rough guide to developing an irrigation schedule based on a soil sample. I would analyze the sites on a per-foot basin then average over the root zone. This would require approximately 1,000 samples with an analysis cost of $30-60 per sample. Total project would require $65,000 to $70,000 and 6 months to complete.

The second project would be to develop a SCADA-like (Supervisory Control and Data Acquisition) program where the data logger information can be remotely accessed. The physically hardest part of this project is complete since the sensors have already been installed. With the sensors installed, many types of loggers and/or communications components can be installed. EID has many facilities scattered about the service district that are already part of the operational SCADA program. Tying the data logger information into this system may be possible. The goal would be to remotely access the information and update irrigation schedules once a day. This information would then be available across the grower portal. This would require a great deal of money and time to complete.

15. Conclusions
I believe that the technology investigated in this project is applicable in nearly all growing conditions. The two caveats with this statement are; 1) an external standard must be used to set the sensor threshold to be used in irrigation scheduling, and 2) EID has no soils that have salinity

issues. The first issue has been addressed by EID through use of a neutron probe. This allowed the empirically derived crop curves and crop coefficients to continue to be used in irrigation scheduling. Current and future technologies may allow different standards to be used to establish irrigation thresholds in site specific locations. This includes, but not limited to, thermal imaging and remote sensing.

The second caveat will have to be addressed in another location. The principle behind Watermark sensor is electrical resistance. As the water level in the soil decrease, the amount of resistance between two electrodes in the sensor will increase. Salinity in the irrigation water and/or soil will change this balance so that the electrical resistance is decreased. As a consequence this will produce artificially low sensor values. This project has demonstrated that sensors in very grainy soil (soil types with high slope values) can still produce reliable data for irrigation scheduling. Therefore, the sensors may still be a viable option for soil with salinity issues.

Further, I found in discussions with Mike Hansen (owner of MK Hansen), that *the average failure rate for installed sensors is approximately 15%*. The major reason for this failure is no or poor soil contact with the sensor. An example is heavy clay soils where the soil will actually shrink away from the sensor as the soil dries leaving the sensor in an air pocket. Without the soil contact, the sensor will display a value of 199 cb. ***Our installation protocol resulted in less than 5 sensor failures with over 1,000 installed (0.5%)***. The failure was usually caused by a nicked wire when trying to install sensor under non-ideal condition. If care is taken during the sensor installation process, the sensors should function for a long period of time with little or no maintenance.

Finally, I believe that this project has achieved its goal of demonstrating that permanently placed soil moisture sensors can replace neutron probe in an irrigation scheduling program.

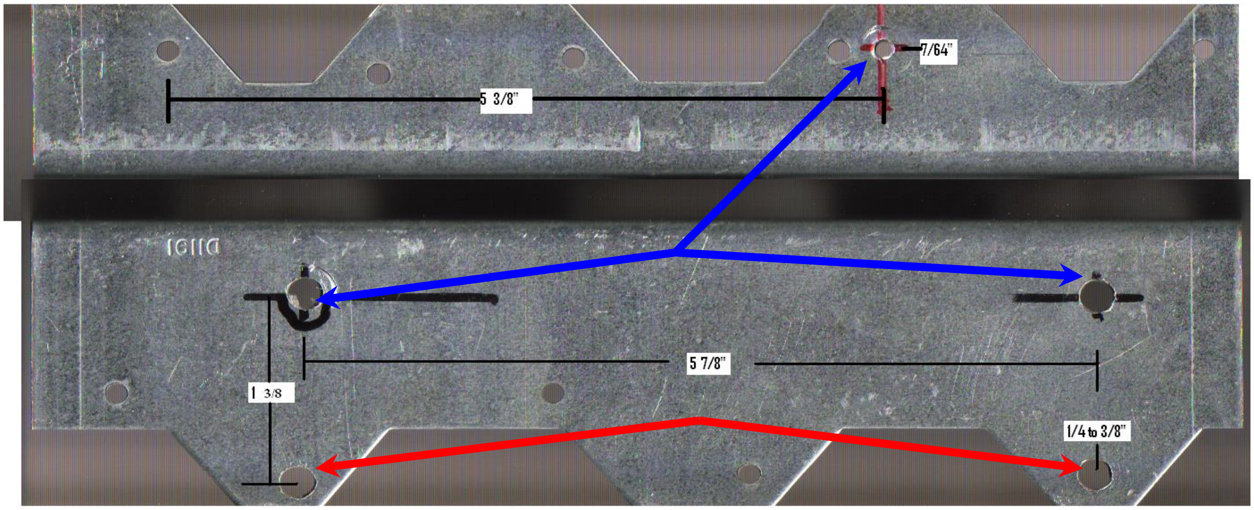

Figure 1
L90 Simpson Strong Tie. This figure shows the location and diameter of the extra holes. The top portion shows the two holes used to mount the data logger to the bracket. The lower portion shows the u-bolt holes. Ultimately only one u-bolt was utilized in the majority of the sites. The blue arrows show the location of the new holes. The red arrows show holes that were enlarged to accommodate the u-bolts.

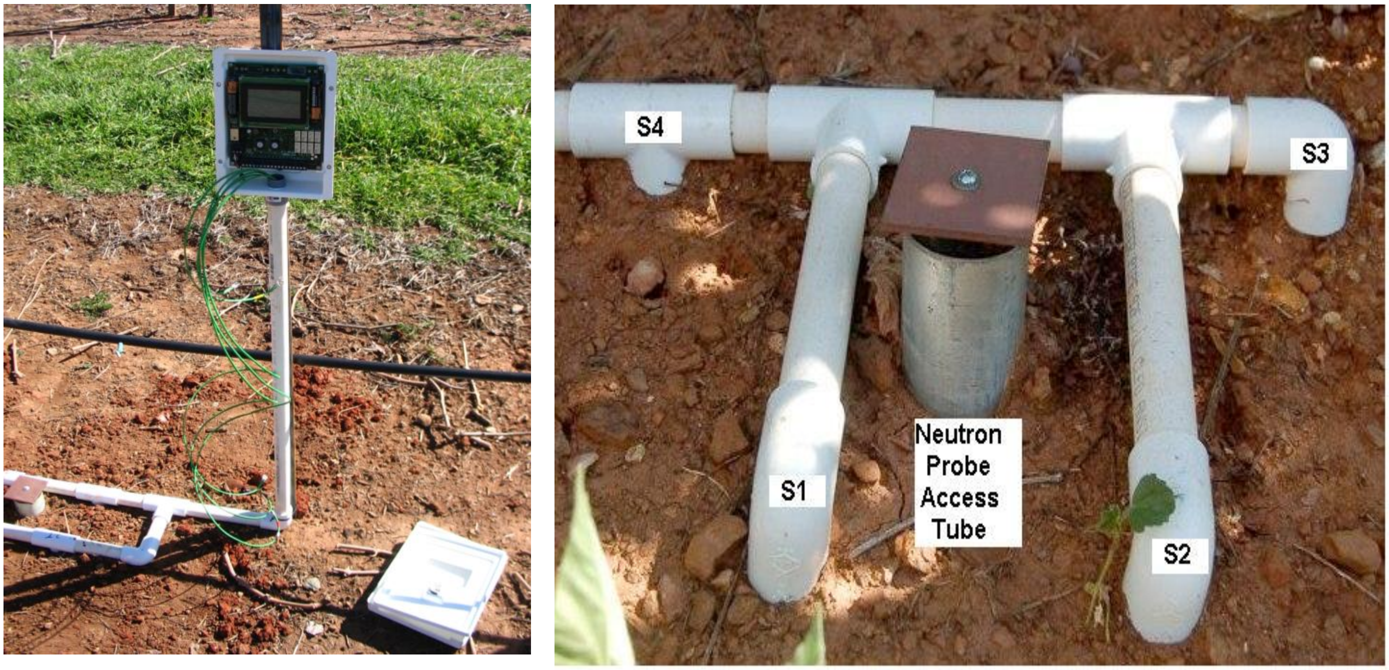

Figure 2
Data logger and sensor site installation. The left-hand picture shows a typical installation of a data logger and sensors at a neutron probe monitoring site. This shows the position of the neutron probe access tube, PVC matrix, grape stake, and data logger. The right-hand picture shows a close-up of the access tube and sensor locations. (The access tube is capped so that small animals do not fall down the hole.) The sensors are arranged in a consistent pattern to reduce mistakes when re-placing sensors.

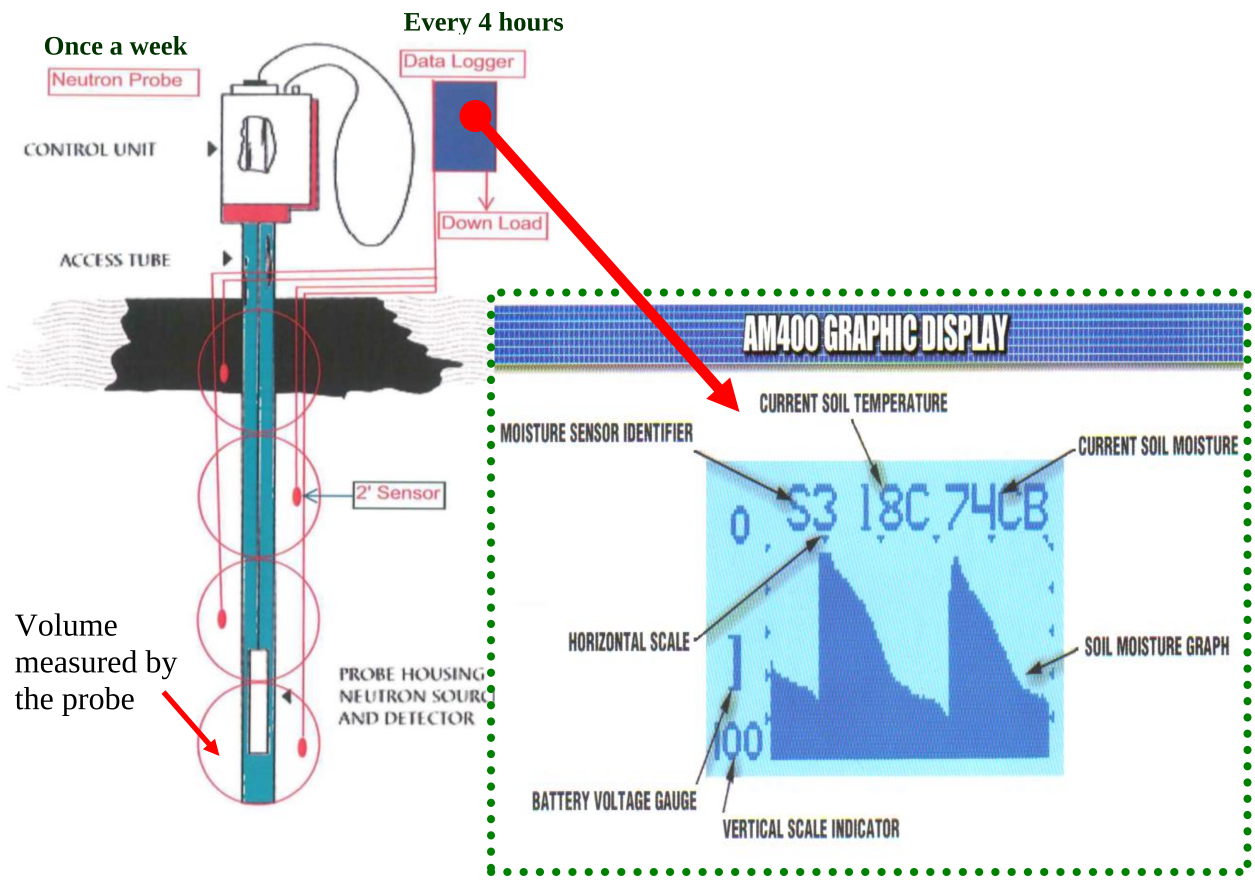

Figure 3
Neutron probe cartoon and data logger display. A cartoon showing the neutron probe, access tube, data logger, and sensor positions for a wine grape monitoring site. The red circles show the approximate soil volume measured by the neutron probe. The sensors are installed within the volume and at approximately the same depth as the neutron probe measurements are taken. Also included is the graphic display as seen by the grower in the field. This particular screen is showing the soil moisture status at a depth of 3' and the current soil temperature at 2'. The neutron probe only measures values when it is used while the data logger records values every four hours.

Soil Position	Field Capacity	Probe Read	Depletion	Sensor Value
4’	**4.20 in/ft**	**3.58 in/ft**	**0.62 in/ft**	**54 cb/ft**
3’	**3.66**	**3.23**	**0.43**	**66**
2’	**3.79**	**3.17**	**0.62**	**64**
1’	**3.32**	**2.52**	**0.80**	**117**
Total	**14.97**	**12.50**	**2.47**	**301**
Average	**3.74**	3.12	**0.62**	**75**

Figure 4
Weekly data analysis for one site. This is an example of the weekly data collected from a grape site during the irrigation season. This site is measured through 4’ in one-foot intervals. The field capacity is measured at the start of the season when the soil is saturated and has inches of water per foot (in/ft) as units. The probe read is the weekly measurement during the irrigation season. Depletion is calculated by subtracting the probe read from the FC. Direct comparison on a per foot basis demonstrates that there is no consistent relationship between the sensor value and the depletion value. The averages are calculated by summing the values over the root zone then dividing this value by the depth of the root zone. Further, comparison of the field capacities demonstrates that the soils in EID are variable over the vertical direction as well as the horizontal direction.

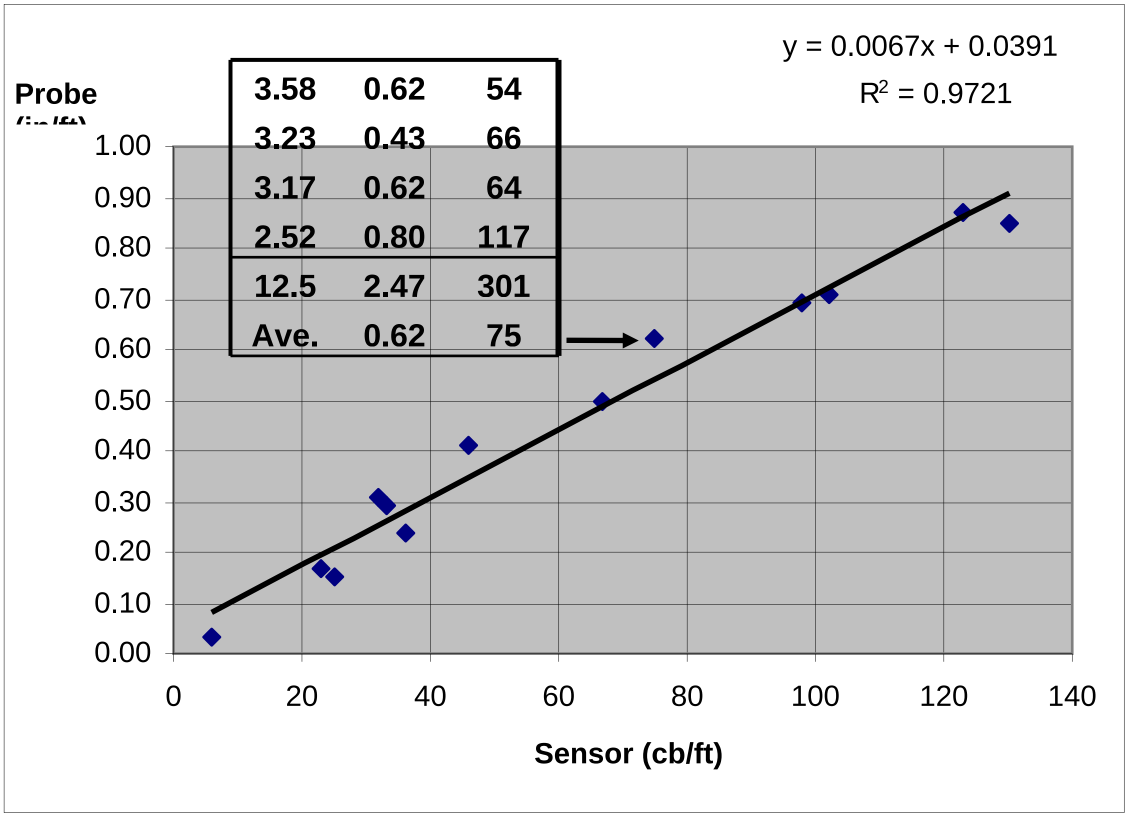

Figure 5
Entire irrigation season data analysis for one site. This graph represents the data analysis for one grape site over an entire irrigation season. The inset table is the same information presented in Figure 4. This table generates one data point on the xy-scatter plot. The line is the best fit linear trend line for this data series. The slope (*m*) is equal to 0.0067 and the y-intercept (*b*) is equal to 0.0391. This information is displayed at the upper right. The R^2-value is 0.97 and this is displayed just below the linear equation. This linear equation can now be used as a calibration curve to convert sensor values (x) into neutron probe values (y) so that historic crop curves can be used for irrigation scheduling at this site.

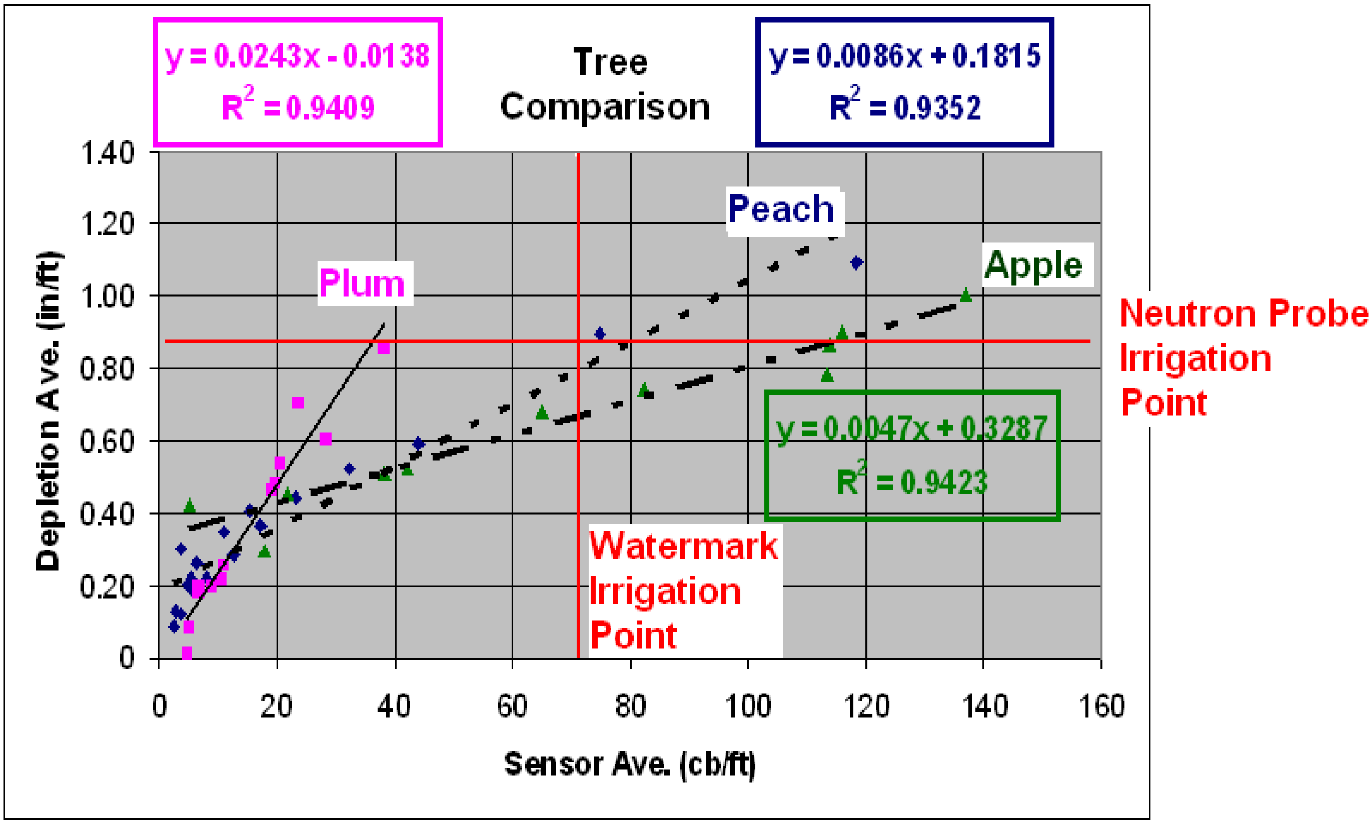

Figure 6
Multiple site data comparison. This figure compares the data analysis of three tree crop sites. All of the sites have R^2-values greater than 0.9 indicating a very strong linear relationship between the neutron probe and sensor values at each site. The vertical red line indicates the irrigation threshold recommended by Irrometer. The horizontal red line indicates the irrigation threshold as determined by the neutron probe. This figure demonstrates that sensors have site specific sensitivities to soil moisture.

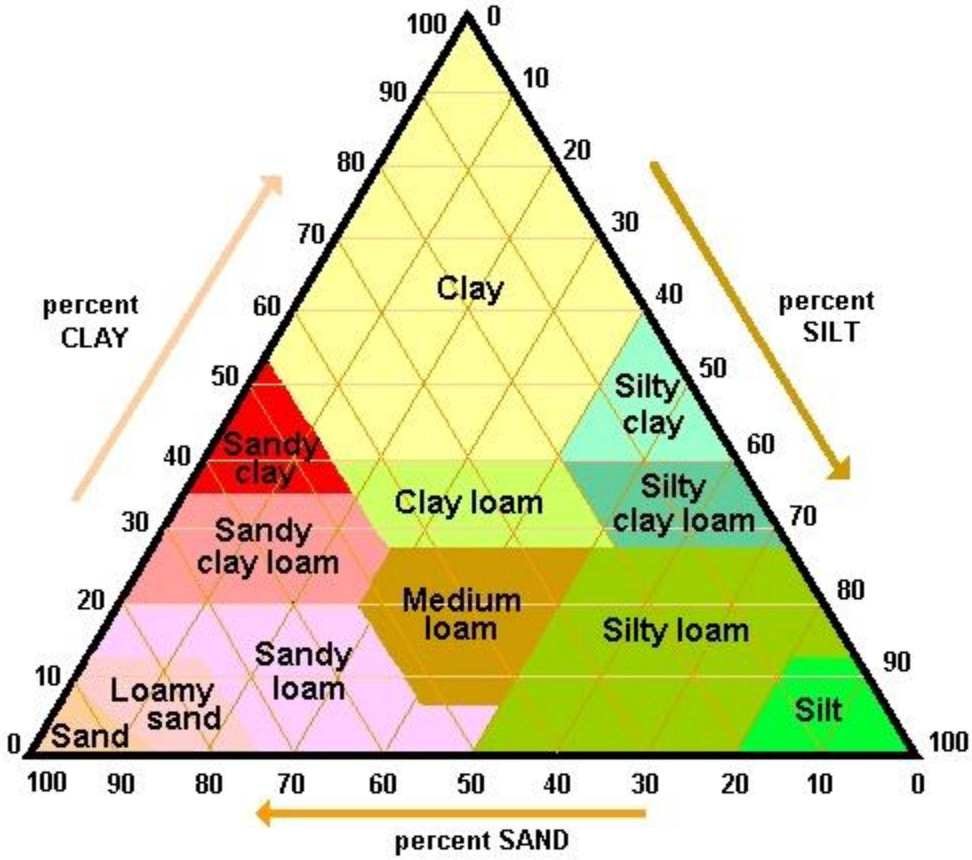

Figure 7
The Soil Triangle. This triangle has been developed to define soil types based on particle sizes. A soil sample is first sifted with a 2 mm mesh screen to remove large gravel and/or large organic pieces. A texture test is run on the remaining sample to determine the percentages of the various sized particles that remain. Sand is defined as 0.05-2 mm, silt is 0.002-0.05 mm, and clay is <0.002 mm. The soil sample can then be placed in this triangle. The original soil survey data used local features and/or terminology to develop soil class names. This complicates analysis when trying to compare soils over a large geographical area.

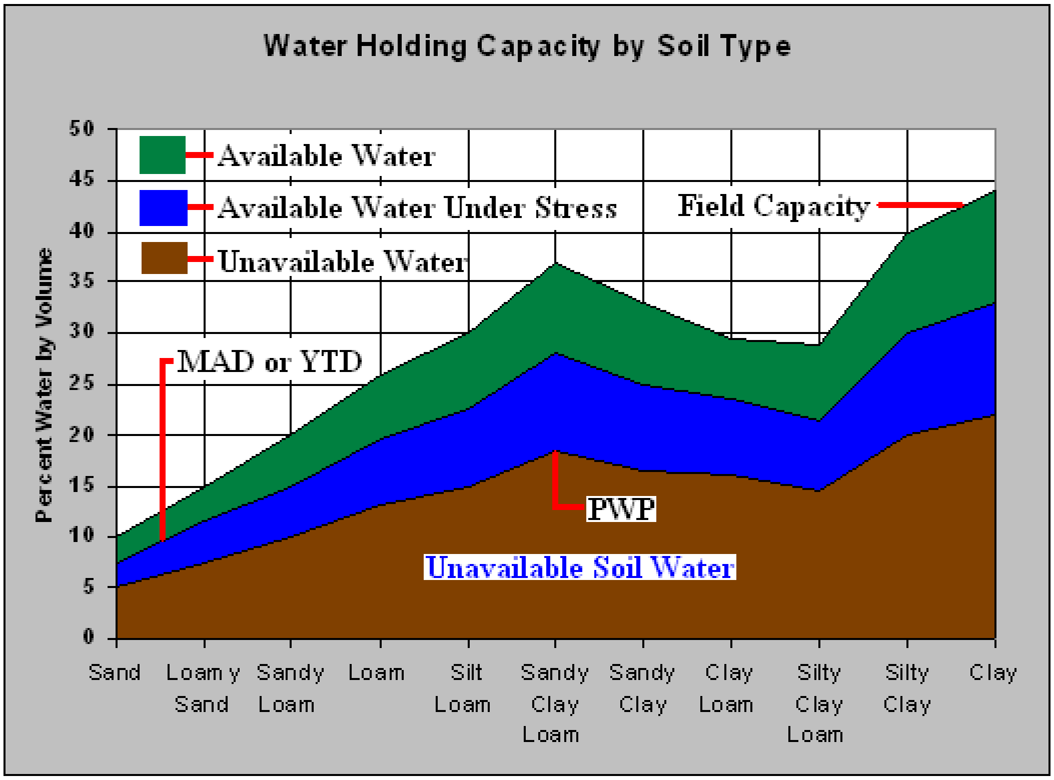

Figure 8
Soil triangle water holding capacity. This is a graphical representation of the water holding capacity of the various sub-regions found in the soil triangle. The water holding capacity of the soil increases, but not linearly, as the size of the particles decrease. This graph can then be used to set initial irrigation scheduling values, such as the MAD, based on the root zone and the soil type found at a specific site. In this figure MAD is the managed allowable depletion, and PWP is the permanent wilt point.

Appendix A: Data analysis results. Data is sorted in descending R^2-values. Values displayed are the site key (4-digit unique identifier), slope (*m*), y-intercept (*b*), and R^2-values.

Site Key	*m* =	*b* =	R^2 =
1365	0.0133	-0.0273	0.98
1122	0.006	0.024	0.9766
1001	0.0077	0.0409	0.9757
1264	0.0417	-0.2407	0.973
1028	0.008	0.0715	0.9665
1104	0.0072	0.1257	0.9654
1359	0.0103	0.0432	0.9644
1302	0.0196	-0.1	0.9628
1102	0.0035	0.197	0.9619
1072	0.0098	-0.0629	0.9616
1030	0.0128	-0.0477	0.961
1087	0.0072	0.0999	0.96
1085	0.0081	0.0679	0.9555
1188	0.0119	0.0815	0.9536
1100	0.008	0.0203	0.9535
1320	0.0023	0.1265	0.9524
1186	0.0179	0.0895	0.952
1208	0.0143	-0.0761	0.9508
1138	0.0152	0.1197	0.9495
1297	0.0077	0.0516	0.9474
1261	0.0156	0.0032	0.9473
1260	0.0134	0.0075	0.9463
1011	0.007	0.0819	0.9427
1251	0.0171	0.1425	0.9408
1328	0.0086	0.1815	0.9352
1353	0.0206	0.2205	0.9338
1031	0.0114	0.0837	0.9328
1170	0.0155	0.1332	0.9301
1060	0.0066	0.0501	0.9299
1299	0.0039	-0.0125	0.9296
1308	0.0072	0.0388	0.9278
1073	0.0076	0.0884	0.9259
1278	0.0056	0.0317	0.925
1174	0.0035	0.1129	0.9244
1095	0.0059	0.2561	0.9242
1016	0.011	0.1082	0.9236
1230	0.0078	0.0958	0.9234
1015	0.0065	0.1833	0.9231
1051	0.0041	0.0646	0.9215
1033	0.0226	0.0705	0.9207
1027	0.0054	0.1292	0.9189
1354	0.011	0.0477	0.9185

1103	0.0087	0.1325	0.9184
1113	0.0057	0.0174	0.9171
1123	0.0037	0.1102	0.9162
1062	0.0066	0.0582	0.9162
1325	0.0031	0.2275	0.9158
1249	0.0129	-0.0648	0.9157
1141	0.0054	0.0505	0.9153
1052	0.0196	0.0711	0.9121
1166	0.0036	0.0991	0.9118
1038	0.0087	0.2077	0.9115
1303	0.0094	0.0915	0.9094
1283	0.0063	0.132	0.9093
1229	0.0094	0.0819	0.9086
1192	0.0034	0.1356	0.9083
1140	0.0201	-0.0615	0.9071
1117	0.0089	0.0713	0.9064
1035	0.0124	0.2003	0.9033
1273	0.0088	-0.024	0.899
1267	0.0076	0.0884	0.8985
1128	0.0038	0.1667	0.8981
1093	0.0063	0.1135	0.8973
1040	0.01	0.5595	0.8955
1063	0.0077	0.1252	0.8916
1153	0.0056	0.1551	0.8898
1182	0.013	0.0704	0.8882
1212	0.0098	0.0702	0.8816
1039	0.0092	0.3775	0.8785
1101	0.0112	0.1201	0.8771
1125	0.0092	0.1957	0.8722
1259	0.014	0.0287	0.8718
1195	0.012	0.1579	0.8704
1194	0.0051	0.063	0.8695
1042	0.0041	0.1904	0.8691
1137	0.0167	0.109	0.8682
1177	0.0091	0.1673	0.8674
1034	0.0068	0.2611	0.8666
1248	0.0085	0.0825	0.8653
1294	0.0049	0.0611	0.8616
1120	0.0032	0.0593	0.8615
1064	0.0072	0.0555	0.8605
1364	0.0098	0.0154	0.8587
1057	0.0006	0.5794	0.8565
1185	0.0038	0.1064	0.8557
1257	0.002	0.1651	0.8539
1019	0.0048	0.1807	0.8537
1151	0.0049	0.1841	0.852
1252	0.0043	0.128	0.8519

1357	0.0093	0.0776	0.8519
1329	0.0179	-0.0507	0.8513
1154	0.0034	0.2014	0.8491
1233	0.0067	0.1728	0.8485
1315	0.0053	0.088	0.847
1074	0.0062	0.0148	0.844
1358	0.0192	-0.093	0.8437
1171	0.0172	0.0034	0.8429
1013	0.0118	0.0262	0.8413
1298	0.0097	0.408	0.8388
1029	0.0075	0.1468	0.8382
1199	0.0057	0.0167	0.8371
1066	0.0133	0.0764	0.8354
1092	0.0051	0.1513	0.8344
1216	0.0016	0.4939	0.8339
1175	0.0033	0.1064	0.8335
1293	0.0101	0.0305	0.8315
1207	0.005	0.2224	0.8304
1300	0.0024	0.1222	0.8302
1286	0.0051	0.2607	0.8287
1032	0.0082	0.3065	0.8286
1270	0.0106	-0.0079	0.8279
1322	0.004	0.211	0.8275
1327	0.0021	0.5573	0.8264
1285	0.0119	0.0917	0.8263
1350	0.0225	0.1563	0.8248
1316	0.0035	0.2121	0.8228
1197	0.0091	0.1171	0.8223
1250	0.0033	0.1105	0.8212
1176	0.0036	0.1522	0.8207
1356	0.00115	0.0447	0.8206
1265	0.0046	0.1866	0.8185
1239	0.0036	0.21	0.8182
1211	0.0066	0.0956	0.8182
1289	0.006	0.2079	0.8151
1008	0.0077	0.3724	0.8144
1361	0.0036	0.1641	0.8144
1010	0.0051	0.1717	0.8124
1254	0.0025	0.2758	0.8124
1284	0.0241	0.2023	0.8102
1351	0.0093	0.0163	0.8089
1362	0.0121	0.0687	0.8087
1118	0.0069	0.3086	0.8054
1253	0.0025	0.0892	0.805
1288	0.0045	0.4008	0.8041
1352	0.0108	0.1557	0.8036
1004	0.0075	0.3867	0.8006

1296	0.0091	0.065	0.8005
1089	0.006	0.1549	0.7995
1324	0.0054	0.4423	0.7986
1314	0.0121	0.2239	0.7968
1157	0.0043	-0.0002	0.7944
1210	0.0042	0.1395	0.7925
1228	0.0213	0.0972	0.7918
1190	0.0036	0.1915	0.79
1143	0.017	-0.0401	0.7891
1193	0.0041	0.1113	0.7887
1090	0.0074	0.0086	0.7885
1012	0.0072	0.1539	0.7879
1132	0.005	0.4833	0.7874
1142	0.0069	0.1057	0.7852
1313	0.0041	0.1207	0.7849
1343	0.0032	0.0978	0.7838
1135	0.003	0.0989	0.7825
1220	0.0453	0.1271	0.7819
1272	0.0043	-0.0011	0.7814
1312	0.0048	0.1789	0.7791
1070	0.005	0.0436	0.7783
1338	0.0081	0.1811	0.7782
1160	0.0043	0.1232	0.7776
1263	0.006	0.2267	0.7768
1097	0.0065	0.2714	0.7757
1196	0.004	0.3677	0.7749
1005	0.0216	0.1446	0.7748
1209	0.0081	0.0947	0.7714
1311	0.0086	0.03756	0.7707
1240	0.005	0.2076	0.7688
1336	0.0051	0.1014	0.7687
1363	0.0051	0.4884	0.7683
1231	0.0168	0.2555	0.7618
1191	0.002	0.1063	0.7605
1237	0.0059	0.2471	0.7588
1046	0.0029	0.4795	0.7586
1238	0.0029	0.0973	0.758
1088	0.0027	0.1272	0.755
1309	0.0062	0.3309	0.7536
1321	0.0058	0.0427	0.7534
1002	0.012	0.1556	0.7528
1099	0.0047	0.2606	0.7526
1258	0.0015	0.561	0.7486
1006	0.0201	0.0373	0.7475
1098	0.0044	0.2073	0.7471
1275	0.0017	0.3243	0.7461
1156	0.0077	0.0311	0.7447

1256	0.0024	0.31	0.7433
1036	0.0181	0.2527	0.7414
1172	0.0051	0.2352	0.7372
1227	0.0055	0.2211	0.7347
1232	0.0072	0.2541	0.7342
1158	0.0075	0.0245	0.7341
1139	0.0135	0.1681	0.7318
1213	0.0034	0.1234	0.731
1245	0.0065	0.1008	0.729
1058	0.0076	0.0541	0.7276
1124	0.0051	0.2727	0.7272
1291	0.0048	0.2449	0.7253
1018	0.0107	0.1994	0.7252
1235	0.0035	0.2972	0.7235
1295	0.0121	0.4655	0.7231
1349	0.0176	0.1265	0.7219
1301	0.003	0.0972	0.7196
1109	0.0088	-0.0051	0.7183
1217	0.0021	0.4831	0.7183
1107	0.0104	0.0531	0.7158
1059	0.0021	0.2137	0.714
1290	0.0077	0.2926	0.7133
1345	0.0073	0.137	0.7125
1126	0.0037	0.1508	0.7116
1246	0.0056	0.0394	0.709
1234	0.0065	0.1919	0.7089
1200	0.0021	0.1896	0.7088
1091	0.0031	0.1926	0.7088
1017	0.0042	0.1825	0.7022
1069	0.0027	0.1834	0.701
1014	0.0186	0.3532	0.6942
1056	0.0049	0.1499	0.6941
1071	0.0021	0.3847	0.686
1214	0.0019	0.4015	0.684
1189	0.0019	0.1236	0.6709
1187	0.0035	0.3287	0.6689
1215	0.0023	0.3159	0.6671
1133	0.0035	0.1058	0.6591
1255	0.0017	0.3469	0.6573
1198	0.0042	0.1697	0.6537
1323	0.0026	0.1893	0.6449
1326	0.0033	0.36	0.6447
1344	0.0024	0.3532	0.6305
1244	0.0029	0.1115	0.6216
1287	0.0036	0.1183	0.6202
1173	0.0077	0.2689	0.6179
1136	0.0032	0.096	0.6127

1068	0.0053	0.2651	0.6045
1243	0.0048	-0.0198	0.5969
1096	0.0041	0.0401	0.3315
1116	0.0075	0.112	0.3097
1346	0.0014	0.3623	0.2041
1221	0.0096	0.3399	0.1958
1310	0.0026	0.2968	0.1532
1280	0.0027	0.3272	0.0913

Appendix B: List of Participating Growers.

Name	
Abel, Evelyn	Larsen, Gene
Adams, Mike	Larsen, Marvin
Barsotti, Gael	Larsen, Ray
Battjes, Hank	Leisz, Doug
Betty, Sage	Lightner, Steve
Boeger, Greg	MacCready, John
Boeger, Justin	Mansfield, Ron
Boggess, William	Marchini, Ed
Bolster, Dave	Mathis, Ken
Brown, Tom	McClone, Mark
Bush, David	McGee, Mike
Bush, Paul	McNatt, Jim
Coalwell, Jim	Meyer, Carlan
Covington, Woody	Norton, Randy
Crose, Rick	O'Halloran, Pat
Davis, Richard	Olivo, Nello
Dealey, Larry	Palmer, John
Delfino, Edio	Perry, Ray
Fausel, David	Plubell, Lowell
Franklin, Jack	Refetto, Donald
Gastaldi, Mike	Reneau, Terran
Geel, Stan	Richter, Viola
Gennis, Mike	Richie, Harriett
Goltz, Ed	Sanborn, Charlene
Goyette, Larry	Sartin, Dwayne
Grace, Steve	Schaefer, Fred
Hacker, Sarah	Scharph, Bob
Hansen, Randy	Scheuner, William
Harris, Bill	Sher, Byron
Herriott, Guy	Smith, Anthony
Hildebrand, Frank	Smith, Matt
Hong, Jong	Taylor, Kirk
Hoover, Chris	Trayser, Laura
Huston, Scott	Vaughan, Mark
Johnson, Bill	Vega, Leonardo
Johnson, Gail	Verzello, Robert
Johnson, Lance	Visman, Brad
Jones, Charlie	Visman, George
Kobervig, Dee	von Huene, Roland
Koel, Bert	Walker, Lloyd
Lahey, Donald	Welk, Dennis
Larsen, Earl	Witters, Bob
	Zirkle, Sherrie