Deep Root Irrigation

ET Project Number: ET15PGE1921

Product Manager: Randall Cole
Project Manager: Philip Broaddus
Pacific Gas and Electric Company

Prepared By: Dr. Dilruba Yeasmin
Center for Irrigation Technology at Fresno State
5370 North Chestnut Avenue - M/S OF 18
Fresno, CA 93740

Dr. David Zoldoske
Center for Irrigation Technology at Fresno State
5370 North Chestnut Avenue - M/S OF 18
Fresno, CA 93740

Timothy Jacobsen
Center for Irrigation Technology at Fresno State
5370 North Chestnut Avenue - M/S OF 18
Fresno, CA 93740

Issued: March 9, 2019

ACKNOWLEDGEMENTS

Pacific Gas and Electric Company's Emerging Technologies Program is responsible for this project. It was developed as part of Pacific Gas and Electric Company's Emerging Technology – Technology Evaluation program under internal project number ET15PGE1921. The Center for Irrigation Technology on the campus of California State University, Fresno conducted this technology evaluation for Pacific Gas and Electric Company with overall guidance and management from Randall Cole. For more information on this project, contact Phil Broaddus at P1B8@pge.com.

LEGAL NOTICE

This report was prepared for Pacific Gas and Electric Company for use by its employees and agents. Neither Pacific Gas and Electric Company nor any of its employees and agents:

(1) makes any written or oral warranty, expressed or implied, including, but not limited to those concerning merchantability or fitness for a particular purpose;

(2) assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, process, method, or policy contained herein; or

(3) represents that its use would not infringe any privately owned rights, including, but not limited to, patents, trademarks, or copyrights.

ABBREVIATIONS AND ACRONYMS

PG&E	Pacific Gas and Electric Company
CIT	Center for Irrigation Technology at Fresno State
CSUF	California State University, Fresno
DRI	Deep Root Irrigation
ETc	Potential Evapotranspiration
ETo	Evapotranspiration
gph	Gallons per hour
GPR	Ground Penetrating Radar
kWh	Kilowatt-hour
micro m/s	Micro Meter per Second
NRCS	Natural Resources Conservation Service
UAL	University Agricultural Laboratory at Fresno State

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

Items **Pg No.**

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF FIGURES (CONTINUED)

Figures **Pg No.**

LIST OF TABLES

LIST OF TABLES (CONTINUED)

Tables **Pg No.**

EXECUTIVE SUMMARY

With a target of reducing applied water, and thus resulting in pump energy savings, a new irrigation technique, Deep Root Irrigation (DRI), was tested in comparison to a conventional dual-line surface drip irrigation system (inline drip emitters) in a young almond orchard on the University Agricultural Laboratory (UAL) at California State University, Fresno. The project began in February 2016 with the DRI installation and the monitoring equipment operational in the field in July 2016. The first year, the experiment started late in the growing season and ended in November of 2016. In the first season, 12.5 percent less water was applied directly into the root zone (underground) through the DRI system as compared to trees irrigated by dual-line surface drip irrigation which was designed to fully meet the almond trees' irrigation needs. In the middle of the second season (January 2017 to November 2017), the water applied through the DRI system was reduced another 12.5 percent to 25 percent. In the third season of the study (January 2018 to November 2018), 25 percent less water was applied through the DRI system compared to the fully irrigated surface drip system.

The principal objective of this study was to determine if less water could be applied, improving water use efficiency, with the DRI system without impacting crop growth and yield. Water use efficiency would be improved by eliminating surface evaporation and improving the amount of water available to the tree directly in the root zone. Any reduction in applied water would translate directly to energy savings due to reduction of energy for pumping. The basic premise of this study was that a reduction in applied water losses directly correlates to energy savings provided crop health and yields are maintained.

Key components monitored during this study included tree growth, yield, root development, soil moisture level within the root zone, total applied water, and water stress. Data was collected for both DRI-treated and in-line surface drip irrigated control almond trees. There are two varieties of trees that were tested: 1) Nonpareil and 2) Supareil. These trees of two varieties were planted at alternate rows in the field. There were three treatments (DRI-treated) and three control plots randomly distributed in the experimental area. Each plot had three nonpareil and three supareil variety, total 6 data collection trees with about 24 border guard trees surrounding them from all sides to make sure no interaction or bias was introduced from adjacent plots. Two adjacent treatment and control plots together made one replicate, therefore there were three replicates in this experiment.

In the Nonpareil almond variety (one of the major almond varieties in the San Joaquin Valley), DRI-treated trees showed no statistically significant difference (with a 95 percent confidence interval) in tree height compared to surface drip irrigated control trees in the three replicated plots during the project. Similar results were found for fruit setting and leaf growth at critical growth stages for this variety. However, the trunk girth measurement showed a statistically significant difference. Data was collected six times in approximately six-month intervals throughout the life of the three-year project. The DRI-treated trees' trunk girth was about 5 percent smaller than surface drip irrigated control trees in 60 percent of the total collected data but the DRI-treated trees were 6 percent bigger in trunk girth than the control trees in about 30 percent of the total collected data. In the remaining 10 percent the data were equal. Since this was a young orchard, the first harvest was in the final season of the project after the DRI irrigation system was fully established in the field.

For the Nonpareil variety, on an average, the DRI-treated trees produced about 8 percent lower yield of almonds than the surface drip irrigated control trees. Even though 25% less water was applied through DRI, the yield loss was not directly proportional. It was a lot less, about 8%. In the context of severe drought in California with continued unavailability of irrigation water and increased dependence on groundwater, fallowing of orchards is one the

biggest challenges that California growers are facing. In that regard, using DRI can be a promising alternative option for California growers. In regard to nut quality, data was collected only on one parameter: 100 count of nut weights and in the Nonpareil variety, no difference was found.

For the second almond variety, Supareil, no statistically significant differences were found in leaf and fruit setting between the DRI-treated and surface drip irrigated control trees. However, there were significant differences found for tree height, trunk girth, and yield.

Irrigation water demand was estimated using an evapotranspiration (ET) based irrigation scheduling model and the amount of irrigation water applied to the field was monitored throughout the life of the project. By design, the DRI-treated trees were getting less water locally than the surface drip irrigated control trees. Monitoring was necessary to ensure that over-irrigation was eliminated and did not introduce any form of bias into the study. Data analysis showed under-irrigation for a few months in the year 2016 and part of 2017 for both DRI-treated and control trees but this was adjusted in the year 2018. The goal of applying less water locally to the plants through the DRI technique was achieved in the experimental field.

At the same time of the day, soil moisture at two different root zone depths (6 inches and 24 inches) of the DRI-treated and surface drip irrigated control trees were almost at the same level (or very close) in most cases, as found from real-time soil moisture monitoring. The irrigation schedule was maintained the same for both plots in all three replications. System pressure was maintained the same from the main valve as well as locally using pressure-compensating emitters. The flow rate was tested at different pressures in the Center for Irrigation Technology Hydraulics Laboratory for the DRI units and the pressure-compensating drip emitters at the beginning of the study and before installation in the field.

Crop growth and yield was not impacted proportionally as a result of reduced applied water to the trees using the DRI method. With a 25% reduced applied water, about 8% yield loss was found. Therefore, it is suggested that more research is needed to determine if additional and/or improved placement of the DRI emission devices would help to increase nut yields compared to the yields achieved in the control plots.

Finally, given an overall 49 percent pumping efficiency and 189 feet of Total Dynamic Head measured at that particular pump station, and a 3.5 ac-ft./acre/year water application through surface drip, the energy savings due to water savings in the first year of the study for 12.5 percent reduction in water applied would be 173.8 kWh/acre/year, and for the 25 percent reduction in water applied in the second year of the study, it would be 345.6 kWh/acre/year.

The study was conducted in one soil type, Hanford sandy loam. Therefore, it is not possible to comment on how the DRI technique will perform in other soil types. From a maintenance standpoint, in each growing season, especially after harvest, about 10 percent of the DRI equipment had to be changed or replaced which can be considered normal wear and tear. With conventional surface drip emitters the similar amount of wear and tear could be expected. Monitoring through sap flow sensors was helpful to determine if the plants were under water stress and in the summer of 2016, and part of 2017, some stress was recorded in the DRI-irrigated trees. Possible causes may have been under-irrigation and/or bad data from the sensor. For the most part, this problem was resolved by adjusting irrigation applications as well as more frequent monitoring and maintenance of sensors. Using ground penetrating radar (GPR) scanning throughout the life of the project, this experiment could not find any evidence to support that the DRI technique may help in fostering stronger vertical root growth providing a better anchor for the plant. This study was conducted on a total of 229 trees, of which 95 trees were irrigated with the DRI technique as the treatment group, and the remaining 134 trees with dual line surface drip irrigation as the control group. This number includes all the trees in the experimental plots and also border guard trees. The results of this study can be statistically limited by the size of the sample. A larger sample size with more data points would make the study results more reliable. Also, observing the growth and yield after a few more years with less water applied through this new irrigation technique may provide a better indication on its sustainability over time.

Overall, from this study it can be established that DRI is a promising technique of irrigating almond orchards with the potential of up to 25 percent water savings and corresponding energy savings with minor compromises to crop growth and yield especially for the Nonpareil almond variety in the context of reduced availability of irrigation water and risk of fallowing orchards. DRI may help to improve water use efficiency as well. Some site-specific criteria might be applicable such as soil type, weather pattern, management, and maintenance, etc. In the San Joaquin Valley, especially in the summer months (from mid-June to mid-August) when the temperature is very high, closer monitoring of the trees might be necessary to avoid water stress while irrigating at a reduced amount using the DRI technique. Since DRI equipment are placed underground, and thus prevent water loss that could be caused by evaporation and runoff, other similar techniques of irrigation directly underground such as buried drip emitters may offer similar water and energy-saving potential.

INTRODUCTION

OVERVIEW

During frequent and persistent drought situations in California, the loss of surface water supplies causes more growers to become solely dependent on groundwater sources. This shift increases demand for groundwater withdrawals, which leads to further drops in the water table level. These results in an increase in the overall amount of groundwater pumped and increased required lift (energy) due to falling water tables. Any improvement in water use efficiency in the field can potentially reduce the increased energy required to meet the crop water demand. Since a major portion of California water is used for farming, more efficient ways to irrigate farmlands will lead to significant water savings. It is estimated that dependence on groundwater increases by nearly a third, from 29 percent in a normal year to 39 percent under drought conditions (Choy, J et al 2019). More efficient irrigation systems will lead to less applied water.

The concept of Deep Root Irrigation (DRI) is relatively new. DRI provides the opportunity to irrigate directly to the root zone of a plant or tree. This process works using a conventional drip system by installing a porous pipe with tubing to the drip system. The porous portion goes underground, placed at the desired depth and distance from the plant. Water is transported via tubing that connects to a conventional pressure-regulated emitter. When water is applied through the system, it is transmitted through the porous pipe to the adjacent soil.

Given the large amount of statewide agricultural water used for almond production, the proposed project was designed to achieve the following objective:

- Save energy through water savings by reducing direct evaporation and runoff from the soil surface since water will be applied directly into the root zone. Water will also be saved by reducing water consumption by weeds.

STUDY AREA

The almond orchard was new, consisting of about six acres planted in November 2014. Figure 1 shows the study area denoted by red boundaries. In the field, there were 20 trees in a North-South direction, except for the first three rows from the East side that have a fewer number of trees (17, 18, 19 trees). There were 31 rows of trees in an East-West direction. Generally, tree spacing was 20 ft in both directions with some exceptions at the beginning and end of the rows. There was a total of 614 trees in the field. Two varieties of almonds were planted in the field – Nonpareil and Supareil. They are planted in alternating East-West direction rows. Nonpareil is the most widely planted variety in the San Joaquin Valley and the entire State of California. Nonpareil is taller, more upright, and slender while Supareil is shorter and wider.

In the field, there are two different types of soils according to Natural Resources Conservation Service (NRCS) soil survey: 1) Hanford sandy loam and 2) Tujunga loamy sand. Almost 75 percent of the field is Hanford sandy loam with 25 percent Tujunga loamy sand (Figure 2). Hanford sandy loam has 68 percent sand whereas Tujunga loamy sand has 80 percent sand. Hanford sandy loam has a saturated hydraulic conductivity (Ksat) of 14 – 42 micro m/s whereas Tujunga loamy sand has a saturated hydraulic conductivity of 42 – 141 micro m/s. Available water capacity (in/in) for Hanford sandy loam is .10 - .15 and for Tujunga loamy sand it is .05 - .08.

Figure 1: DRI almond field on Fresno State Farm

Eastern Fresno Area, California (CA654)			
Map Unit Symbol	**Map Unit Name**	**Acres in AOI**	**Percent of AOI**
GtA	Greenfield sandy loam, 0 to 3 percent slopes	0.0	0.0%
Hc	Hanford sandy loam	6.0	76.6%
TzbA	Tujunga loamy sand, 0 to 3 percent slopes	1.8	23.3%
Totals for Area of Interest		**7.9**	**100.0%**

Figure 2: Soil type according to NRCS soil survey

Since the NRCS soil map is old, the original soil survey in Fresno County started in early 1900 and was updated time to time (USDA NRCS website: https://www.nrcs.usda.gov/wps/portal/nrcs/surveylist/soils/survey/state/?stateId=CA).

Therefore, to get most current soil condition information, soil samples were collected systematically by hand auger from 21 different locations that cover the north, middle and south side of the field as well as east to west (Figure 3). All samples collected were five feet deep. Soil type was examined by experienced soil scientists using hand feel testing and determined to be Hanford sandy loam. The homogenous soil area of the field was identified through this test and for the experimental design and plot layout of this study; this finding is taken into consideration so that variability in irrigation water use due to different soil type can be minimized.

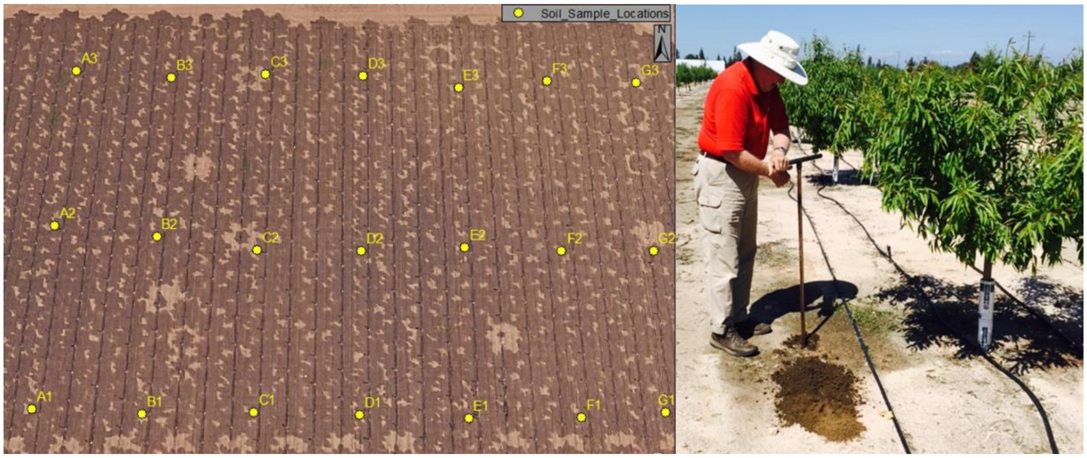


Figure 3: Field testing of soil type

There were 12 rows of trees included in the experimental design with a total of 229 trees. Ninety-five trees (41 percent of the total 229 trees) were irrigated with the DRI system (treated); the remaining 134 trees (59 percent of the total 229 trees) were irrigated with dual line surface drip irrigation (control). To avoid variability in the soil type, the experimental plots were not arranged by row, but treatments and control were assigned within the row. Two guard rows of trees were also established to negate influence from adjacent emission devices. The experimental plot layout is provided in Figure 4 below.

In the experimental plot layout in Figure 4:

- Yellow highlighted area shows all the plot locations in the field.
- DRI treatment trees are highlighted in green and labeled as DRI
- Surface drip irrigated control trees are highlighted in red and labeled as CR
- Three replicates with the combination of blocks DRI-CR, CR-DRI and DRI-CR are shown with arrows
- C1 to C31 right to left (East to West) direction shows the number of rows and R1 to R39 (bottom to top) South-North direction shows trees in each row

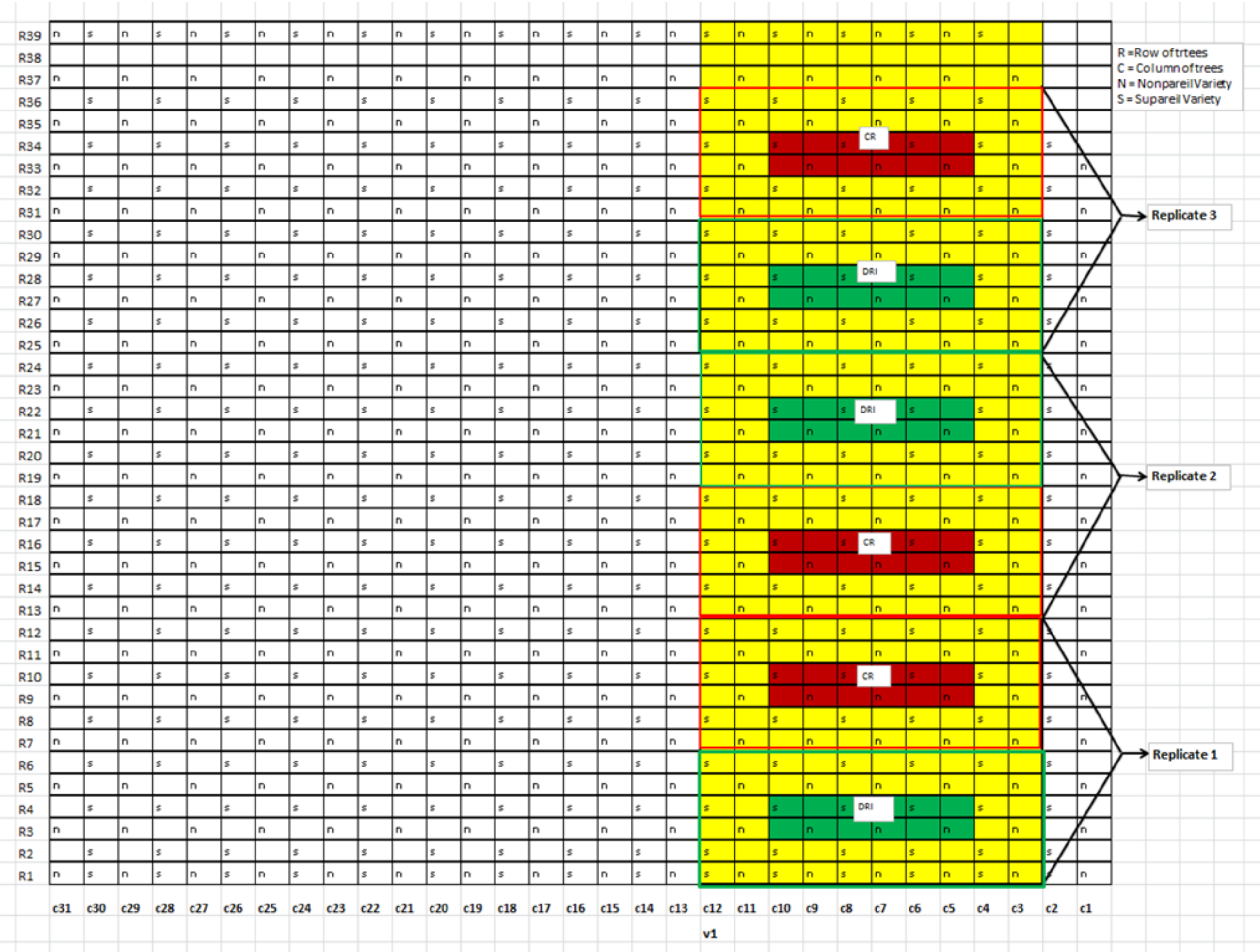


Figure 4: Experimental plot layout

EXISTING IRRIGATION SYSTEM INFRASTRUCTURE

The main pump station for the almond field is located at the northeast corner of the field. It has the following features: a pump, pressure-reducing valve, pressure-relief valve, filter, and a flow meter. The irrigation water source is surface water which comes from a reservoir across the street. The main irrigation line is underground. Table 1 and Figure 5 below have some specifics of the main irrigation setup.

Table 1: Almond field main pump station infrastructure

Item	Specification	Quantity	Status
Pump	Lift pump, 30 HP	1	Installed
Filter	Sand media filter	1	Installed
Valves (used in the main pump station)	Pressure-reducing valve and pressure-relief valve	1	Installed
Well	Active (rarely used)	1	Installed
Reservoir	Surface pond	1	Installed
Flow meter	Records flow from main pump station	1	Installed

Figure 5: Main pump station at northeast corner of DRI field

INSTALL DRI AND ALL OTHER MONITORING INSTRUMENTS

Installing all the required instruments and making required changes to the irrigation system were some of the most important and crucial parts of this project. The instrument installation for this project was done in multiple steps and took several months. The major instrument installations that were completed for this project were:

1) Installation of DRI
2) Installation of soil moisture sensors (SENTEK and Delta-T soil moisture sensors)
3) Installation of sap flow sensors (Dynamax Inc.)
4) Installation of flow meters, pressure transducers, and remote data loggers

INSTALLATION OF DRI:

DRI Equipment:

DRI equipment is made out of two parts: 1) small perforated attachment/soaker hose attachment with 2) spaghetti tubing (1/4th inch tubing for connecting DRI unit with Drip emitters) (figure 6). The perforated attachment comes in different sizes depending on which crop would be irrigated (figure 6(right)). For example: DRI-3 (for potted plants), DRI-6 (bushy plants), DRI-12 (orchard and vine trees), and DRI-18 (large shade trees). For the experimental almond orchard, DRI-12 was used.

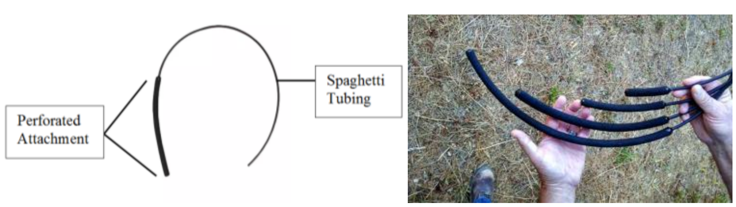


Figure 6: DRI equipment with two parts (left), and different sizes (right)

The diagram below shows the design of the DRI unit as it is inserted underground in the root zone (https://deeprootdistribution.com/products.html).

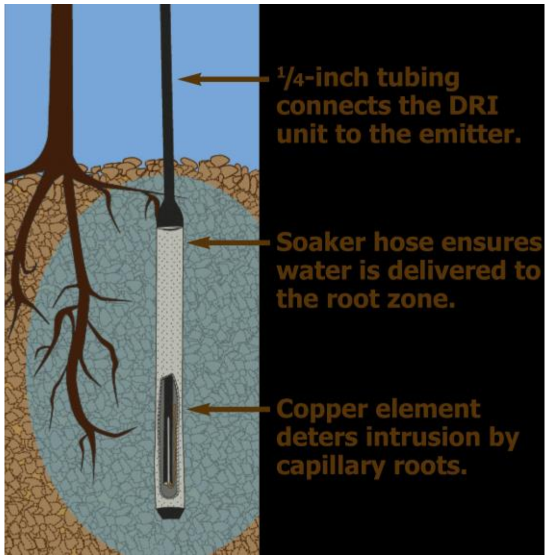


Figure 7: DRI equipment design as inserted underground

DRI Installation:

For installing DRI instruments, DRI LLC. provided the DRI tubes and made suggestions regarding installation. With a combined effort from CIT, Fresno State employees and students, and DRI LLC staff, three DRI equipment per tree were installed (Figure 8). The standard installation requires two DRI units per tree but in this case, to implement the desired flow rate for the experiment, three DRI units per tree were installed as suggested by the manufacturer. Following the experimental design, all the trees that were under DRI plots were instrumented with DRI equipment. The placement locations around each tree were determined by DRI LLC.

Figure 8: DRI instrument installation

The three DRI equipment that were attached with each tree were applying water in three different flow rates through drip emitters 1) in the first year of the study, it was 2 gph, 1 gph and ½ gph to implement 12.5 percent less water application compared to surface drip irrigated control trees which were irrigated with two 2 gph emitters per tree; 2) in the second year of the study, it was 2 gph, 2 gph and 2 gph, total 6 gph per tree to implement 25 percent less water application compared to surface drip irrigated control trees which were irrigated with four 2 gph emitters, total 8 gph per tree. Ninety-degree angle penetrations were used for inserting the DRI equipment at about a two-foot distance from the tree base and about one foot deep in the soil as suggested by DRI LLC.

INSTALLATION OF SOIL MOISTURE SENSORS:

The need for accurate soil moisture measurements in the field made installation and operation of the soil moisture sensors very important for this study. Two different brands of soil moisture sensors, SENTEK Drill and Drop soil moisture sensor and Delta-T soil moisture sensor, were installed in the experimental field. Soil moisture sensors were installed in both DRI and control areas and moisture data was collected from variable depths of soil depending on type of moisture sensor probe.

INSTALLATION OF SENTEK SOIL MOISTURE SENSORS

SENTEK Drill and Drop probes were installed at DRI and control tree locations to monitor soil moisture in the field. Two sensors were rented by DRI LLC. for use during the life of the project. Two locations, one in the DRI irrigation area and another in the control (conventional drip irrigation) area of the field, were selected to install the probes. Sensors were calibrated by the manufacturer before and after installation. Since these sensors and telemetry setup are expensive, two sensors were decided to be cost effective. However, it was not possible to install soil moisture sensors for all three replicates or for all DRI and control plots. The sensors were placed at the locations that seemed reasonably free from edge effect.

Figure 9 shows the two SENTEK soil moisture probes per location. Each sensor was placed at a one-foot and two-foot distance from the tree base to track not only vertical movement of water through the soil but also horizontal movement. Figure 9 below also shows the installation process.

Figure 9: SENTEK soil moisture probe installation

INSTALLATION OF DELTA-T SOIL MOISTURE SENSORS

The Delta-T soil moisture sensors were acquired from Dynamax with two sets of sensors, one for DRI-treated and one for control trees (Figure 10). The sensors collect data at two different depths - 6 inches and 24 inches. Installation of these soil moisture probes were calibrated by manufacturer and were installed by Dynamax staff with the assistance of Fresno State field technicians and students. Field level calibration was also done by Dynamax staff. Figure 10 shows the Delta-T installation in the field.

Figure 10: The Delta-T soil moisture probe installed at the DRI field

Other Instrumentation and Data Logging

To keep track of how much irrigation water was applied in the field; flow meters were installed in the experimental plot, in the main valve, and also in some of the service lines. Pressure transducers were installed in the main line and also two other service lines to track the pressure required to deliver the irrigation to the field.

Figures 11 and 12 respectively show the system design and the complete system for flow meter and pressure transducer installed in the field at the main valve with data logging and telemetry system. Soil moisture sensor has a separate, stand-alone data logging and telemetry system that is not incorporated in this system to avoid complicacy. This system consisted of a Seametrics "MJR-200-2P" reed switch flowmeter, a voltage output based pressure transducer manufactured by Irrometer called "RSU-V_100". Campbell Scientific's CR206X data logger was used to monitor and record flow and pressure data. A 10-Watt solar panel was used to continuously power up the whole system using 12V-7 AmpHr battery. A 900 MHz radio antenna was used to communicate wirelessly with base station computer located at the California Water Institute office at Cedar and Bullard. LoggerNet software from Campbell Scientific was used to connect to the data logger remotely and hence access data. A remote desktop application was used on Windows-based computers to access the base station computer remotely using its IP address and hence the data logger through LoggerNet software.

System Design

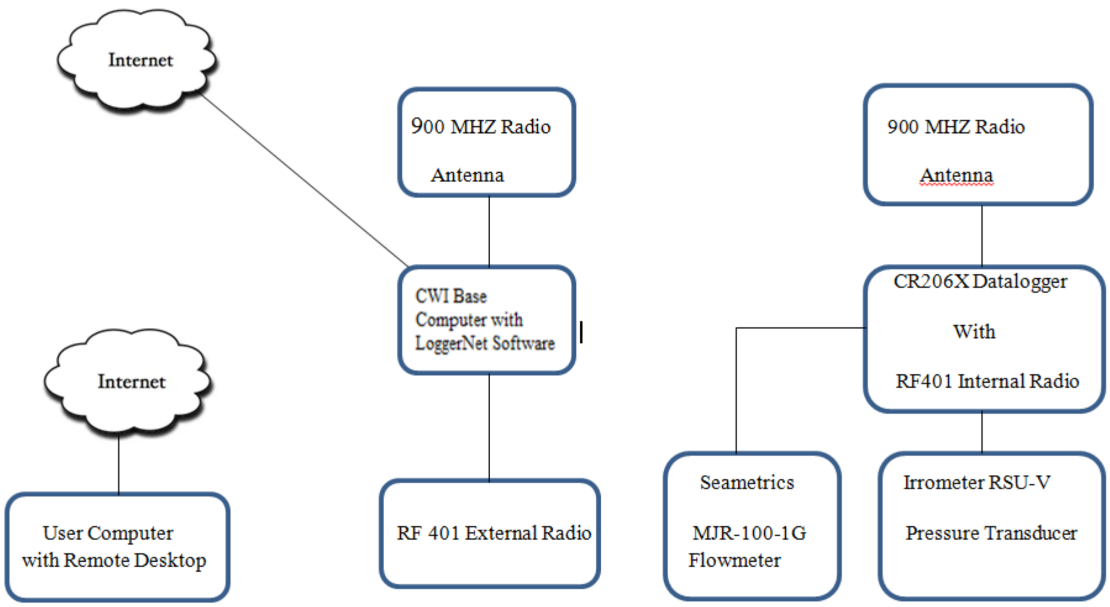


Figure 11: Flow diagram of system design

Figure 12: Installation of the complete system (with data logging and telemetry system)

Installing Sap Flow Sensor

Sap flow sensors are some of the latest technology used to measure the sap flow directly from plants that gives an indication of direct water consumption by plants (Figure 13). The underlying mechanism of these sensors is that they are energy balance sensors that can measure the amount of heat carried by the sap which is converted into real-time sap flow in grams or kilograms per hour. The sensors should not be harmful to the plants as they only heat the plant tissue from 1°C to 5°C (~2° F to 9° F) (http://dynamax.com/products/transpiration-sap-flow/dynagage-sap-flow-sensor).

For this study, since new irrigation technology was being evaluated, it was crucial to know if the plants were under water stress at any time and helped ensure the trees health. A direct, early indicator of water stress in plants was very valuable for this study. Sap flow sensors were acquired from Dynamax Inc. and installed in the field. A total of 8 sensors were acquired in the first year of the study. Four sensors were installed in two DRI irrigated trees (two sensors per tree) and the data was averaged. Same number of sensors and averaging protocol was followed for surface drip irrigated control trees. However, due to high cost, the number of sensors was reduced to half for both DRI irrigated and surface drip irrigated trees in the third year of the study. This data was just a reference dataset, therefore spending too much on this did not seem to be useful.

Figure 13: Sap flow sensors at DRI-irrigated almond tree branches

WATER DEMAND ESTIMATION:

A good water demand estimation and proper irrigation scheduling is the first step to make sure efficient water use by plants for their growth, development and yield. If water demand estimation and irrigation scheduling can be modeled carefully, it can eventually help toward any effort for increasing water use efficiency. This can eventually lead to saving irrigation water and energy. Most common irrigation scheduling methods are dependent on three approaches. Those three approaches are 1) monitoring of crop 2) monitoring of soil and 3) water balance. Soil water balance based irrigation scheduling works under the main idea that irrigation needs to be applied in the field to compensate the water losses that cannot be fulfilled by rain or any other water source. This leads to the question, how water losses happen in a crop field? It mainly happens through evapotranspiration. Evapotranspiration is a combined process of evaporation of water from ground and wet portion of plant and transpiration of water through leaf stomata. It is very important to estimate crop evapotranspiration correctly to estimate water demand of a crop. Estimating

Evapotranspiration correctly is not easy. Reference Evapotranpiration (ET_0) can generally be determined either depending on historical evapotranspiration data or real time evapotranspiration on reference crop such as well-watered grass or alfalfa from climatic data and complex equations developed experimentally. For State of California, California Irrigation Management Information System (CIMIS) provides current ETo information for most of the major agricultural regions of the state.

Evapotranspiration of an orchard crop is not same as the grass or alflfa evapotranspiration. Therefore, crop coefficient is required for the particular orchard crop to modify the reference evapotranspiration value for the orchard crop (Schwanki, L et. al., UC ANR publication 8212). Crop co-efficient is usually denoted by Kc depends on light absorption by the canopy, canopy roughness, crop physiology, leaf age, surface wetness etc. (Snyder, R.L. 2007). With the development of canopy, transpiration by plants increases compared to evaporation from soil. Therefore young trees have smaller evapotranspiration rate than mature trees. Growers, in addition to estimate from experience, can make good estimate of irrigation using reference evapotranspiration (ETo), and crop co-efficient (Kc) data as this estimation method is commonly practiced and is supported by scientific research.

The experimental almond field was located on the University Agricultural Laboratory at the California State University, Fresno campus. CIMIS (California Irrigation Management Information System) weather station number 80 is also located on the Fresno State Campus Farm within about a half mile from the field. Because of this advantage of proximity, the reference Evapotranspiration data (ETo) and other weather-related data were utilized from CIMIS weather station number 80.

For the irrigation water demand estimation, the potential evapotranspiration, ETc of the orchard crop is generally calculated by the equation:

ETc = ETo x Kc…………………………………………………….. (1)

Where, ETc = Potential Evapotranspiration,

ETo = Reference Evapotranspiration

Kc = Crop Coefficient

(Schwanki, L et. al., UC ANR publication 8212)

Weekly water demand for the experimental almond orchard was calculated for the entire active irrigation time for the years 2016, 2017, and 2018. All the tables are provided in Appendix A. For example, May 2018 and June 2018 are represented in Tables 2 and 3 below using Reference Evapotranspiration (ETo) and Crop Coefficient (Kc) data.

Table 2: Weekly water demand for May 2018

Month	Week	Area	Shading	Shading factor	ET_0	K_c	ETc	Application Efficiency	Required Run Time hr/wk.	Design Flow	Flow
		(acre)	%	-		-	in/wk.		hr/wk.	in/wk.	Ac-Ft/wk.
May	1 (1 -7)	1.9	40	0.81	1.51	0.76	0.93	0.932	58.83	1.23	0.19
May	2 (8 - 14)	1.9	40	0.81	1.89	0.76	1.16	0.932	73.64	1.54	0.24
May	3 (15 - 21)	1.9	40	0.81	1.72	0.76	1.06	0.932	67.01	1.40	0.22
May	4 (22 - 28)	1.9	40	0.81	1.83	0.76	1.13	0.932	71.30	1.49	0.24
May	5 (29 - 31)	1.9	40	0.81	0.87	0.76	0.54	0.932	33.90	0.71	0.11

Note: Per Calculation, ETc = (ET_0)*(Kc)* Shading Factor, Required Run Time (hrs/wk) = ETc/Effective Application Rate (.0158)

Table 3: Weekly water demand for June 2018

Month	Week	Area	Shading	Shading factor	ETo	K_c	ETc	Application Efficiency	Required Run Time hr/wk.	Design Flow	Flow
		(acre)	%	-		-	in/wk.		hr/wk.	in/wk.	Ac-Ft/wk.
June	1 (1 - 7)	1.9	40	0.81	2.13	0.85	1.47	0.932	92.82	1.94	0.31
June	2 (8 - 14)	1.9	40	0.81	2.13	0.85	1.47	0.932	92.82	1.94	0.31
June	3 (15 - 21)	1.9	40	0.81	2	0.85	1.38	0.932	87.15	1.82	0.29
June	4 (22 - 28)	1.9	40	0.81	2.18	0.85	1.50	0.932	95.00	1.99	0.31
June	5 (29 - 30)	1.9	40	0.81	0.58	0.85	0.40	0.932	25.27	0.53	0.08

Note: Per Calculation, ETc = (ET0)*(Kc)* Shading Factor, Required Run Time (hrs/wk) = ETc/Effective Application Rate (.0158)

WATER DEMAND AND APPLIED WATER COMPARISON:

A comparison between applied irrigation from flow meter data (actual irrigation applied to the field) and weekly estimated water demand from Tables 2 and 3 is presented below in Table 4. Amount of applied water for year 2017 and 2018 as recorded from the flow meter data and are attached in Appendix E as well.

Table 4: Comparison between actual irrigation applied to the field and water demand according to the model

Month	Week	Estimated Water Demand	Actual Applied Water	Difference
		(Ac-Ft/Wk)	(Ac-Ft/Wk)	(Ac-Ft/Wk)
May 2018	1 (1 -7)	.19	.21	(.02)
May 2018	2 (8 -14)	.24	.23	0.01
May 2018	3 (15 -21)	.22	.15	.07
May 2018	4 (22 - 28)	.24	.17	.07
May 2018	5 (29 -30)	.11	.12	(.01)
June 2018	1 (1 -7)	.31	.23	.08
June 2018	2 (8 -14)	.31	.16	.15
June 2018	3 (15 -21)	.29	.18	.11
June 2018	(22 – 28)	.31	.15	.16
June 2018	(29 – 30)	.08	.0	.08

Table 4 shows that in the above eight-week time frame sometimes water demand was fulfilled by applied irrigation and sometimes there was less water applied in the field than demand. Sometimes the orchard manger was intentionally deficit irrigating the field which is applicable for both DRI-irrigated and surface drip irrigated control plots. Sometimes there were some other field operation related reason and water availability related matter behind that. The existing soil moisture in the field also could be a deciding factor since it was not considered in the water demand model. The orchard manager was in charge of making field operation related decisions. In summary, the overall water application should have the same impact on DRI treated and surface drip irrigated trees since the reduced irrigation through DRI was applied to the field locally.

SOIL MOISTURE COMPARISON:

Soil moisture sensors provided soil moisture data from the DRI and control plots at two different depths (6 inches and 24 inches) to monitor available moisture for the almond trees. As mentioned earlier, soil moisture sensors were placed in two different locations in the field one for monitoring the DRI-irrigated trees and one for surface drip irrigated control trees. Twenty five percent less water was applied through the DRI irrigation system in the third year's active irrigation months. Data was collected in real-time and due to the volume of data, it is not possible to represent all the data here. Figures 14 to 21 show that the DRI and control tree area soil has almost the same or a very close level of available water at the same time of the day (midday-between 1 p.m. to 2 p.m.). The irrigation schedule was exactly the same for both DRI and control plot areas.

From this eight-week soil moisture data, a promising trend of the soil moisture level was found. It showed that even though 25 percent less water was applied through DRI, the soil still had almost the same, or very close to, the same level of available water for the trees as did the control plot.

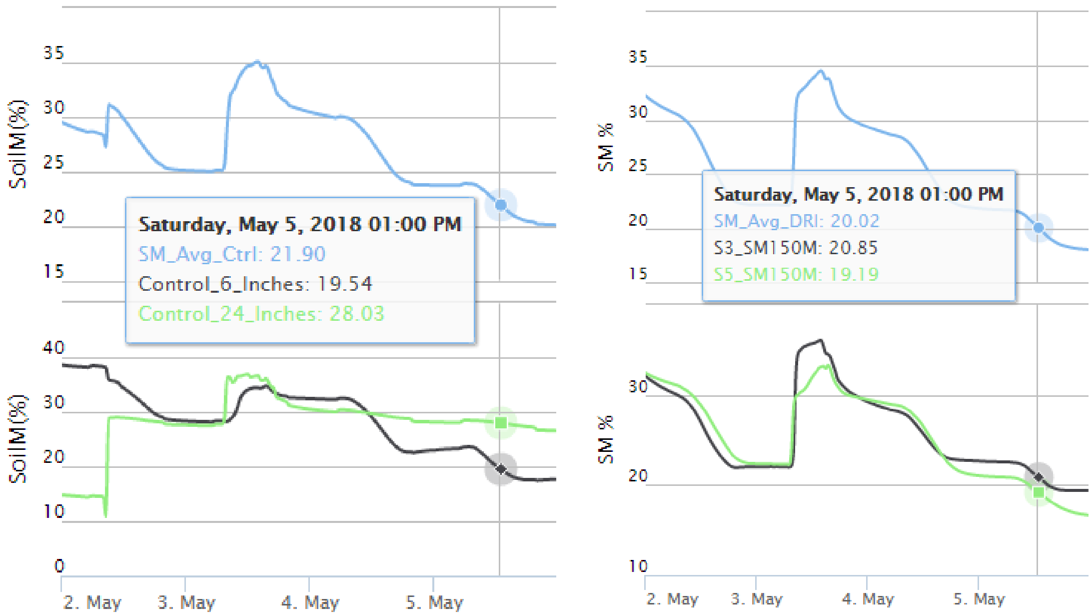


Figure 14: Soil moisture level at the DRI (right) and control (left) trees on May 05, 2018 at 1 p.m.

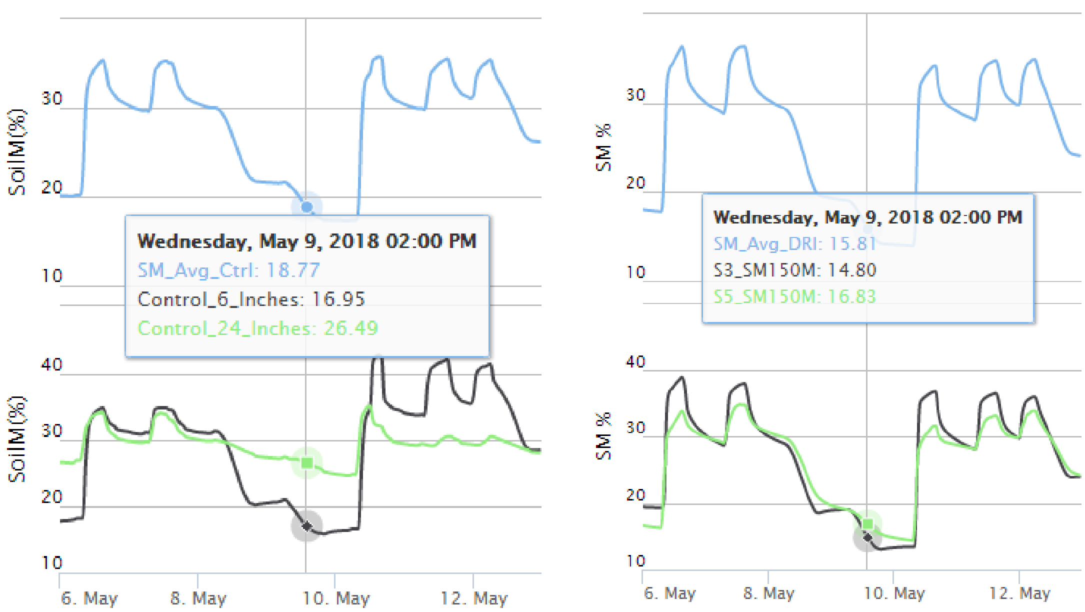


Figure 15: Soil moisture level at the DRI (right) and control (left) trees on May 09, 2018 at 2 p.m.

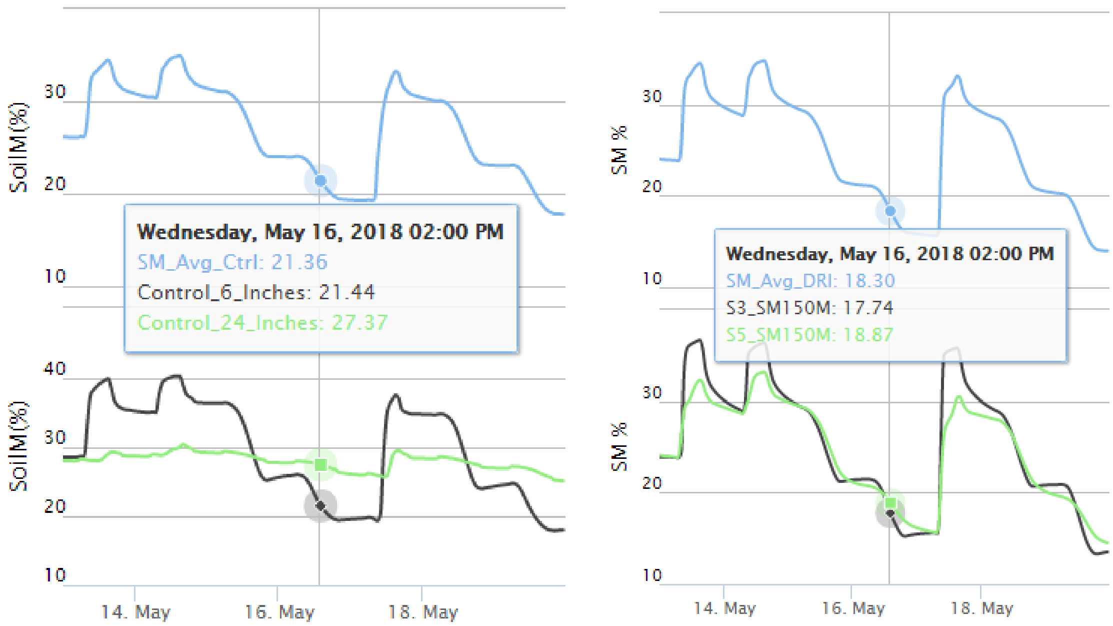


Figure 16: Soil moisture level at the DRI (right) and control (left) trees on May 16, 2018 at 2 p.m.

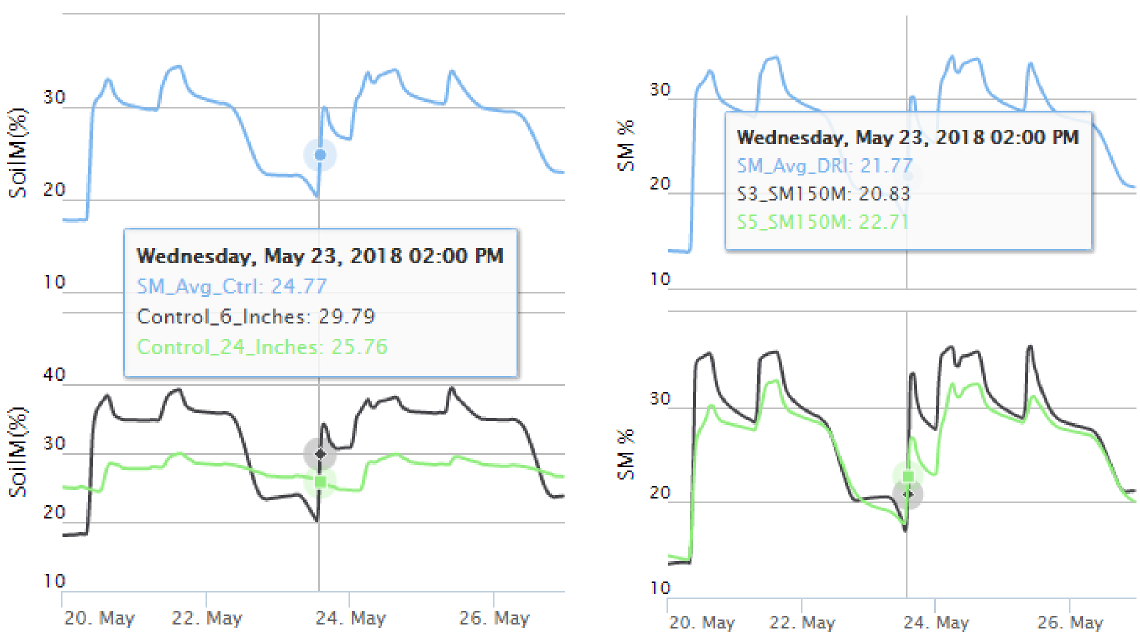


Figure 17: Soil moisture level at the DRI (right) and control (left) trees on May 23, 2018 at 2 p.m.

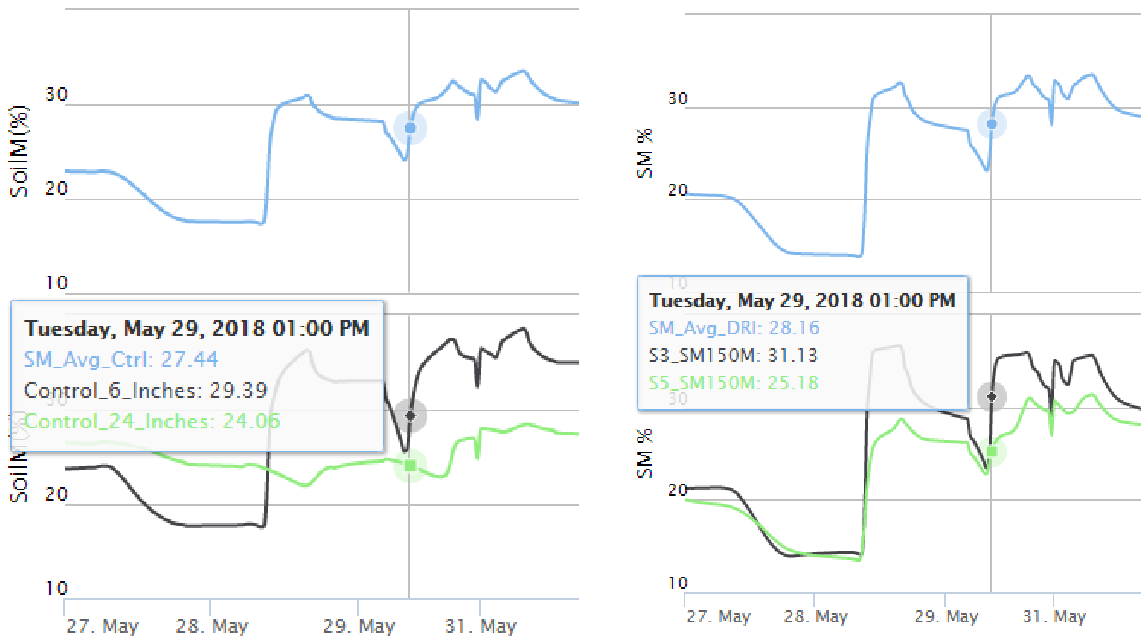


Figure 18: Soil moisture level at the DRI (right) and control (left) trees on May 29, 2018 at 1 p.m.

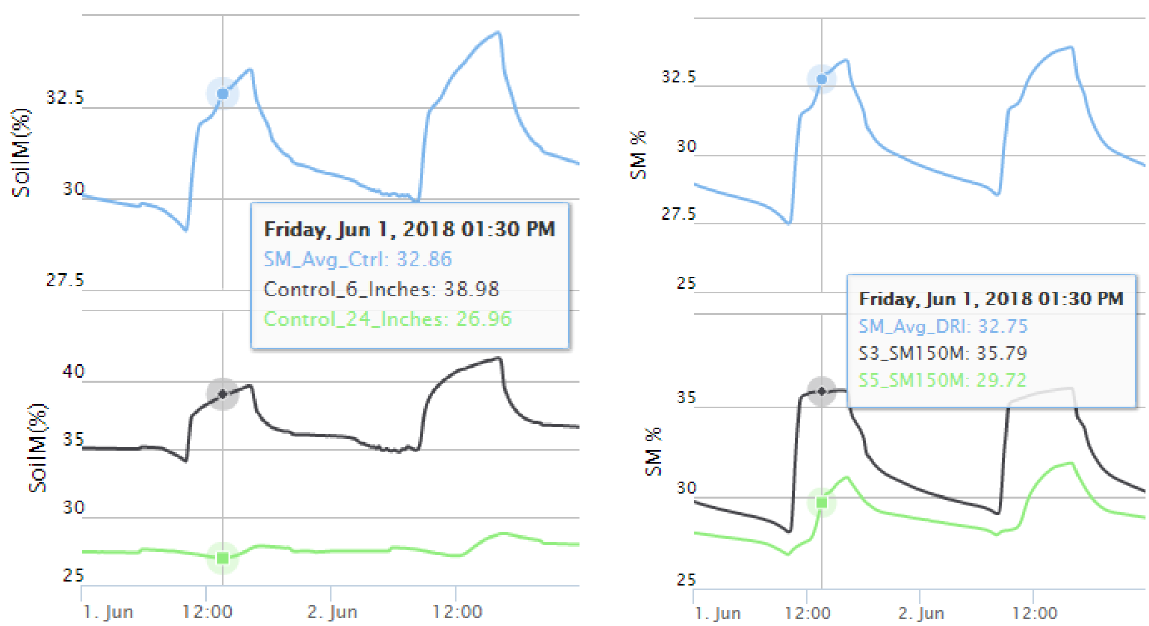


Figure 19: Soil moisture level at the DRI (right) and control (left) trees on June 01, 2018 at 1 p.m.

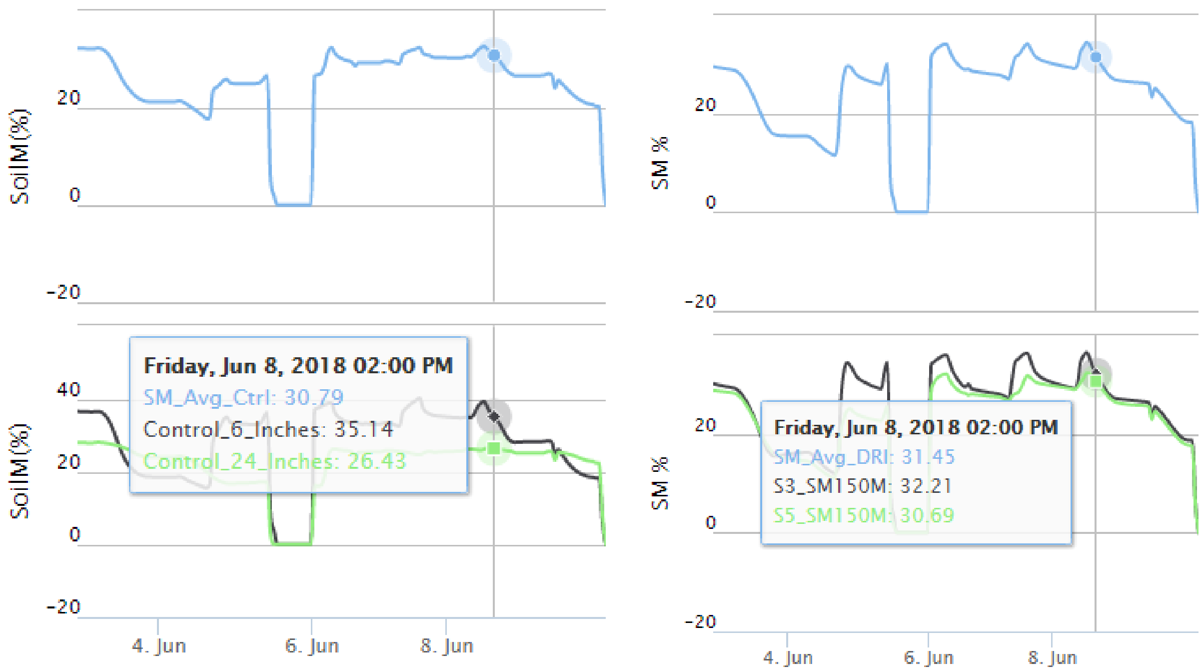


Figure 20: Soil moisture level at the DRI (right) and control (left) trees on June 08, 2018 at 2 p.m.

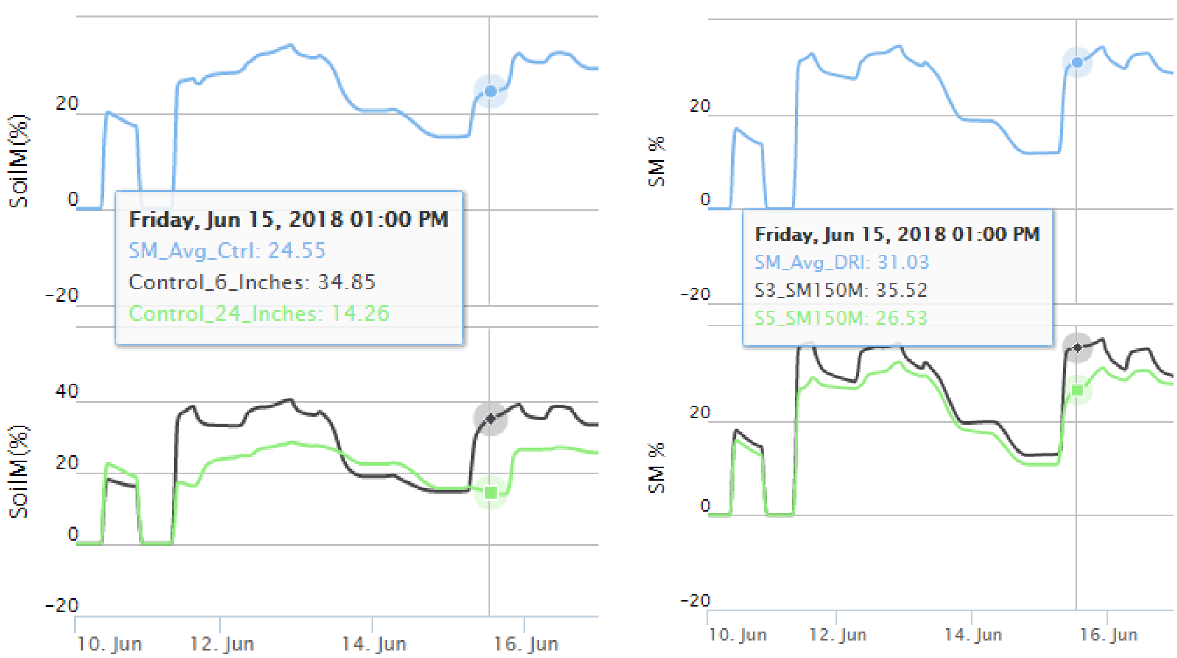


Figure 21: Soil moisture level at the DRI (right) and control (left) trees on June 15, 2018 at 1 p.m.

WATER STRESS AND WATER CONSUMPTION:

Using the sap flow sensors, it was possible to get an indication if the DRI plants were under stress and how much water they were consuming. The stress ratio is represented in Table 5 and the weekly water consumption is represented in Table 6. According to Table 7, the DRI irrigated almond trees are in slight stress in the week of June 4 and in a somewhat moderate level of stress in the week of June 11 and June 18. However, from soil moisture data, it was also evident that available water in the soil was almost at the same level as the control trees. Physical inspection in the field also did not provide any indication that the plant might be under stress. This information was communicated to the sap flow sensor manufacturer and they investigated. According to the manufacturer, the Crop Coefficient value they used in calculating the stress ratio may not have been accurate. They corrected this issue later. It was also observed that the sap flow sensor heated up the tree branch a little bit to get the water consumption reading. As a result of that additional heat, the particular tree branch locally might be under stress but not the entire tree. Frequent replacement of the sensors was done to avoid this problem and the manufacturer agreed with this strategy.

Table 5: Stress in DRI trees

Observation #	Week	Stress Ratio (Weekly Average, in a scale of 0 to 1, 0=most stressed, 1 =no stress)
1	May 21 to May 27, 2018	.5
2	May 28 to June 3, 2018	.63
3	June 4 - June 10, 2018	.41
4	June 11 - June 17, 2018	.36
5	June 18 - June 24, 2018	.35

Table 6: Weekly water consumption by DRI trees

Observation #	Week	Gals/Tree/Week
1	May 21 to May 27, 2018	185.7
2	May 28 to June 3, 2018	191.2
3	June 4 - June 10, 2018	200.9
4	June 11 - June 17, 2018	189.8
5	June 18 - June 24, 2018	183.3

CROP GROWTH COMPARISON:

Crop growth data were collected on all the data collection trees in all plots in the three replicates. Data was collected for: 1) bloom count, leaf and fruit settings on a biweekly basis from March 2018 until May 2018; 2) tree height and trunk girth from the first year of the project (2016), twice a year until the third year of the project (2018); and 3) crop yield data (at the third year of the project (2018) (Figure 22).

All these datasets were compared for DRI-treated and control dual-line surface drip irrigation treated trees periodically and with a final comparison in the third year of the project. A paired t-test was performed to determine if the difference between them was statistically significant.

Figure 22: Crop growth measurements at different stages

In the Nonpareil almond variety (one of the major almond varieties in the San Joaquin Valley), DRI-treated trees showed statistically no significant difference (with a 95 percent confidence interval) in tree height compared to surface drip irrigated control trees in the three replicated plots during the project.

```
T-TEST PAIRS=All_NP_Height_DRI WITH All_NP_Height_Control (PAIRED)
  /CRITERIA=CI(.9500)
  /MISSING=ANALYSIS.
```

T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	All_NP_Height_DRI	12.5741	54	2.48111	.33764
	All_NP_Height_Control	12.7315	54	2.21767	.30179

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	All_NP_Height_DRI & All_NP_Height_Control	54	.881	.000

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	All_NP_Height_DRI - All_NP_Height_Control	-.15741	1.17387	.15974	-.47781	.16300	-.985	53	.329

Note: Sig(2 tailed) value >.05 means there is no difference between the two groups

Figure 23: Nonpareil variety tree height comparison statistical analysis result

Similar results were found for fruit setting and leaf growth at critical growth stages for this variety.

```
T-TEST PAIRS=Fruit_NP_DRI WITH Fruit_NP_Control (PAIRED)
  /CRITERIA=CI(.9500)
  /MISSING=ANALYSIS.
```

T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Fruit_NP_DRI	3.4444	63	6.03158	.75991
	Fruit_NP_Control	5.5556	63	6.32909	.79739

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Fruit_NP_DRI & Fruit_NP_Control	63	.001	.996

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Fruit_NP_DRI - Fruit_NP_Control	-2.11111	8.74018	1.10116	-4.31230	.09007	-1.917	62	.060

Note: Sig(2 tailed) value >.05 means there is no difference between the two groups

Figure 24: Nonpareil variety fruit setting comparison statistical analysis result

```
T-TEST PAIRS=Leaf_NP_DRI WITH Leaf_NP_Control (PAIRED)
  /CRITERIA=CI(.9500)
  /MISSING=ANALYSIS.
```

T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Leaf_NP_DRI	19.0794	63	7.79020	.98147
	Leaf_NP_Control	18.4444	63	7.16348	.90251

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Leaf_NP_DRI & Leaf_NP_Control	63	.729	.000

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Leaf_NP_DRI - Leaf_NP_Control	.63492	5.53086	.69682	-.75801	2.02785	.911	62	.366

Note: Sig (2 tailed) value >.05 means there is no difference between the two groups

Figure 25: Nonpareil variety leaf growth comparison statistical analysis result

However, the trunk girth measurement showed a statistically significant difference. The statistical analysis result is provided in Appendix B. Data was collected six times in approximately six-month intervals throughout the life of the three-year project. Since there are three data collection trees in each treatment replicate, it generates 18 data points for each replicate. The DRI-treated trees' trunk girth was about 5 percent smaller than surface drip irrigated control trees in 60 percent of the total collected data but the DRI-treated trees were 6 percent bigger in trunk girth than the control trees in about 30 percent of the total collected data. In the remaining 10 percent the data were equal.

Table 7: Difference in tree height between DRI and control trees in Nonpareil variety

	Non Pareil								
	Replicate 1			Replicate 2			Replicate 3		
Date	DRI	Control	Diff (DRI-Control)	DRI	Control	Diff (DRI-Control)	DRI	Control	Diff (DRI-Control)
	(feet)	(feet)	(feet)	(feet)	(feet)	(feet)	(feet)	(feet)	(feet)
	9.0	9.5	-0.5	9.0	9.0	0.0	8.5	10.0	-1.5
11/18/2016	8.5	9.0	-0.5	8.5	9.0	-0.5	8.5	9.0	-0.5
	9.0	10.0	-1.0	8.5	11.0	-2.5	8.5	10.5	-2.0
	11.0	10.0	1.0	11.0	11.2	-0.2	10.0	11.5	-1.5
6/15/2017	11.0	10.5	0.5	10.5	12.0	-1.5	10.5	10.5	0.0
	11.2	11.0	0.2	11.0	11.5	-0.5	10.0	11.5	-1.5
	11.5	11.5	0.0	12.0	12.6	-0.6	12.2	12.0	0.2
10/27/2017	12.0	11.5	0.5	12.3	12.4	-0.1	11.8	12.0	-0.2
	12.5	12.0	0.5	10.0	12.8	-2.8	11.0	11.0	0.0
	14.0	12.5	1.5	15.0	16.0	-1.0	15.5	15.5	0.0
6/4/2018	13.0	13.0	0.0	15.5	15.0	0.5	14.5	12.5	2.0
	14.0	13.0	1.0	15.0	16.0	-1.0	14.5	14.0	0.5
	15.0	13.0	2.0	14.0	17.0	-3.0	16.0	15.0	1.0
9/18/2018	15.0	13.0	2.0	15.0	16.0	-1.0	15.0	13.0	2.0
	15.0	14.0	1.0	15.0	16.0	-1.0	15.0	14.0	1.0
	15.0	14.0	1.0	14.5	16.0	-1.5	15.0	15.0	0.0
11/2/2018	15.0	14.0	1.0	15.5	16.0	-0.5	14.0	14.0	0.0
	15.0	14.5	0.5	15.0	16.5	-1.5	14.5	14.5	0.0

Table 8: Difference in tree height between DRI and control trees in Supareil variety

	Supareil								
	Replicate 1			Replicate 2			Replicate 3		
Date	DRI	Control	Diff (DRI-Control)	DRI	Control	Diff (DRI-Control)	DRI	Control	Diff (DRI-Control)
	(feet)	(feet)	(feet)	(feet)	(feet)	(feet)	(feet)	(feet)	(feet)
	6.5	8.0	-1.5	9.0	9.0	0.0	8.5	10.0	-1.5
11/18/2016	6.5	7.0	-0.5	8.5	9.0	-0.5	8.5	9.0	-0.5
	7.5	8.0	-0.5	8.5	11.0	-2.5	8.5	10.5	-2.0
	8.5	9.0	-0.5	11.0	11.2	-0.2	10.0	11.5	-1.5
6/15/2017	9.0	10.5	-1.5	10.5	12.0	-1.5	10.5	10.5	0.0
	9.5	10.5	-1.0	11.0	11.5	-0.5	10.0	11.5	-1.5
	10.0	11.0	-1.0	12.0	12.6	-0.6	12.2	12.0	0.2
10/27/2017	10.0	10.9	-0.9	12.3	12.4	-0.1	11.8	12.0	-0.2
	10.0	10.6	-0.6	10.0	12.8	-2.8	11.0	11.0	0.0
	12.5	14.5	-2.0	15.0	16.0	-1.0	15.5	15.5	0.0
6/4/2018	12.0	12.5	-0.5	15.5	15.0	0.5	14.5	12.5	2.0
	13.0	13.0	0.0	15.0	16.0	-1.0	14.5	14.0	0.5
	13.0	14.0	-1.0	14.0	17.0	-3.0	16.0	15.0	1.0
9/18/2018	13.0	12.0	1.0	15.0	16.0	-1.0	15.0	13.0	2.0
	13.0	13.0	0.0	15.0	16.0	-1.0	15.0	14.0	1.0
	13.0	13.0	0.0	14.5	16.0	-1.5	15.0	15.0	0.0
11/2/2018	13.0	13.0	0.0	15.5	16.0	-0.5	14.0	14.0	0.0
	13.0	13.0	0.0	15.0	16.5	-1.5	14.5	14.5	0.0

Table 9: Difference in trunk girth between DRI and control trees in Nonpareil variety

	Non Pareil								
	Replicate 1			Replicate 2			Replicate 3		
Date	DRI	Control	Diff (DRI-Control)	DRI	Control	Diff (DRI-Control)	DRI	Control	Diff (DRI-Control)
	(Inches)	(Inches)	(Inches)	(Inches)	(Inches)	(Inches)	(Inches)	(Inches)	(Inches)
	10.0	10.2	-0.2	11.2	11.8	-0.6	9.5	9.7	-0.2
11/18/2016	9.1	9.1	0.0	9.7	10.0	-0.4	8.5	8.9	-0.4
	9.7	11.1	-1.5	8.9	10.6	-1.8	9.5	8.9	0.6
	12.0	13.0	-1.0	13.0	14.5	-1.5	13.0	13.0	0.0
6/15/2017	12.0	12.0	0.0	15.6	14.5	1.1	12.0	10.8	1.2
	12.0	12.0	0.0	14.0	13.0	1.0	12.0	13.0	-1.0
	13.5	14.0	-0.5	14.0	15.5	-1.5	13.5	14.0	-0.5
10/27/2017	12.5	13.5	-1.0	13.5	15.0	-1.5	13.0	12.2	0.8
	14.0	13.0	1.0	13.0	14.0	-1.0	12.5	13.0	-0.5
	15.5	16.0	-0.5	16.0	17.0	-1.0	15.0	16.0	-1.0
6/4/2018	15.0	14.1	0.9	15.8	16.5	-0.7	14.7	14.3	0.4
	16.0	15.5	0.5	15.0	16.3	-1.3	14.7	14.5	0.2
	16.0	17.5	-1.5	17.0	18.0	-1.0	17.0	17.0	0.0
9/18/2018	16.0	15.0	1.0	17.0	17.5	-0.5	16.0	15.0	1.0
	16.0	16.0	0.0	16.0	17.0	-1.0	16.0	16.0	0.0
	16.0	17.0	-1.0	17.5	18.0	-0.5	17.0	18.0	-1.0
11/2/2018	16.0	15.0	1.0	17.5	18.0	-0.5	16.5	16.0	0.5
	17.0	16.5	0.5	17.0	17.5	-0.5	16.5	16.0	0.5

Table 10: Difference in trunk girth between DRI and control trees in Supareil variety

	Supareil								
	Replicate 1			Replicate 2			Replicate 3		
Date	DRI	Control	Diff (DRI-Control)	DRI	Control	Diff (DRI-Control)	DRI	Control	Diff (DRI-Control)
	(Inches)	(Inches)	(Inches)	(Inches)	(Inches)	(Inches)	(Inches)	(Inches)	(Inches)
	10.9	10.4	0.5	11.2	12.0	-0.8	9.3	10.4	-1.2
11/18/2016	9.7	10.0	-0.4	8.2	9.8	-1.6	8.9	9.5	-0.6
	9.3	10.4	-1.2	10.2	9.8	0.4	8.9	10.9	-2.1
	13.0	10.8	2.2	12.0	14.5	-2.5	12.0	13.0	-1.0
6/15/2017	12.0	12.0	0.0	12.0	13.0	-1.0	13.0	12.0	1.0
	12.0	14.5	-2.5	13.0	12.0	1.0	13.0	12.0	1.0
	14.0	14.5	-0.5	13.0	15.0	-2.0	13.0	13.5	-0.5
10/27/2017	14.0	14.0	0.0	12.5	15.0	-2.5	14.0	13.8	0.3
	13.5	14.5	-1.0	14.5	13.5	1.0	13.0	13.0	0.0
	16.5	16.9	-0.4	17.0	18.0	-1.0	15.0	16.0	-1.0
6/4/2018	16.0	16.0	0.0	14.5	17.0	-2.5	16.0	16.0	0.0
	16.0	17.2	-1.2	17.0	16.3	0.7	15.0	15.0	0.0
	17.5	18.5	-1.0	17.5	19.0	-1.5	16.5	17.0	-0.5
9/18/2018	17.0	17.0	0.0	16.0	18.0	-2.0	17.0	17.0	0.0
	17.0	19.0	-2.0	18.0	17.5	0.5	17.0	16.0	1.0
	17.0	18.5	-1.5	17.5	19.0	-1.5	16.5	17.0	-0.5
11/2/2018	17.0	17.5	-0.5	16.0	18.0	-2.0	17.0	17.0	0.0
	17.0	19.0	-2.0	17.0	18.5	-1.5	17.5	16.0	1.5

Since this was a young orchard, the first harvest was in the final season of the project after the DRI irrigation system was fully established in the field. For the Nonpareil variety, on an average, the DRI-treated trees produced about 8 percent lower yield of almonds than the surface drip irrigated control trees.

Table 11: Difference in Yield between DRI and control trees in Nonpareil and Supareil variety

Nonpareil			Supareil		
DRI Avg Yield (lbs)	Control Avg Yield (lbs)	%Difference	DRI Avg Wt. (lbs)	Control Avg Wt. (lbs)	%Difference
34.2	26.9	-27.14	17.0	17.3	**1.7**
20.70	27.50	24.73	13.40	16.30	**17.8**
20.40	28.10	27.40	10.40	16.60	**37.3**
25.10	**27.50**	**8.33**	**13.60**	**16.73**	**18.96**

In regard to nut quality, data was collected only on one parameter: 100 count of nut weights and in the Nonpareil variety, no difference was found for DRI and control – in both cases it was 122 grams. For the second almond variety, Supareil, no statistically significant differences were found in leaf and fruit setting between the DRI-treated and surface drip irrigated control trees. However, there were significant differences found for tree height, trunk girth, and yield. The statistical analysis results are provided in Appendix B.

Root Growth Monitoring by Ground Penetrating Radar:

Ground Penetrating Radar (GPR) can be used as a non-destructive tool to evaluate downward and lateral root growth. The root system of a tree provides anchorage, water, and nutrient uptake and assists in many other important processes that relate to crop yield. GPR technology was used in this study to evaluate plant root growth for both deep root irrigation and conventional drip irrigation systems without disturbing the tree's root system. It is assumed since DRI irrigates directly to the plant's root zone underground, it will encourage more downward root growth and will help the tree with better anchorage. In addition to water savings, this is assumed to be an extra advantage of having DRI as an irrigation system.

There are two steps in the scanning process: 1) scanning tree roots at the field with the GPR scanner and 2) data processing and analysis using specific software.

To run the GPR scanner around the trees, all the irrigation lines needed to be detached. Also, it would be really time consuming to scan all experimental trees and post process the data. Therefore, a convenient sample of three DRI-irrigated trees and three surface drip irrigated control trees, total six trees form the six plots were selected to conduct the GPR root analysis. Since nonpareil is the most prominent variety in the valley and most of the growers would be interested in it, all these six trees were nonpareil varieties.

The first part was done using the following procedure:

- Select trees for scanning in the field depending on experimental plot layout, existing instrument location, convenience for scanning, etc.
- Create layout of the scan for each tree
- Complete scanning in the field.

The second part was done using the following procedure:

- The scanned files were downloaded and converted to be used in the software
- Root detection and mapping
- The result was analyzed and summarized.

On July 2016, the first/initial scan was done to establish the baseline for comparison. The trees were young (planted in November 2014) and the roots were growing. Scanning was conducted on the same trees in December 2016, October 2017, and October 2018.

SCAN IN THE FIELD:

In the field, each tree was marked with spray paint so that the circular scans could be done properly. Clockwise and inside out direction scans were done for each tree and the scan files were saved. This same routine was followed for every scan.

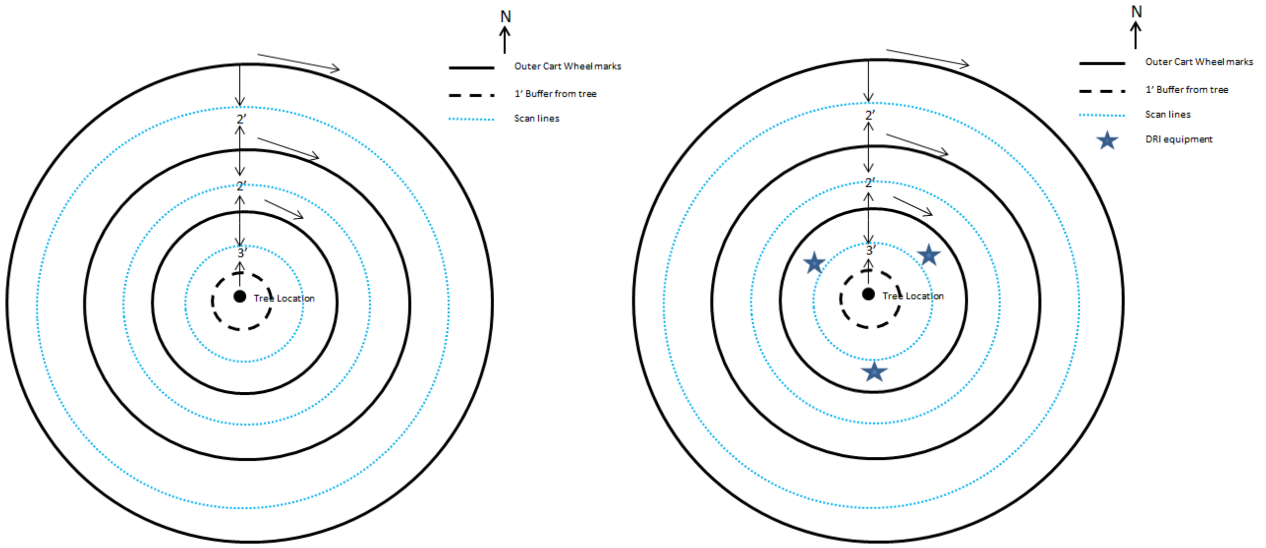


Figure 26: Scan layout for trees with surface drip irrigation (left) and DRI (right) system

Figure 27: Scanning around a tree in the almond field

Three scan files per tree (a total of 18 files for six trees) were processed and used as input in the software for detecting roots. Root detection and mapping results are attached here in the following figures for all the scans. No ground truthing was done for this data since for the living trees' active root system could not be disturbed. For this reason, everything that was primarily recognized as roots by the software may not always be roots.

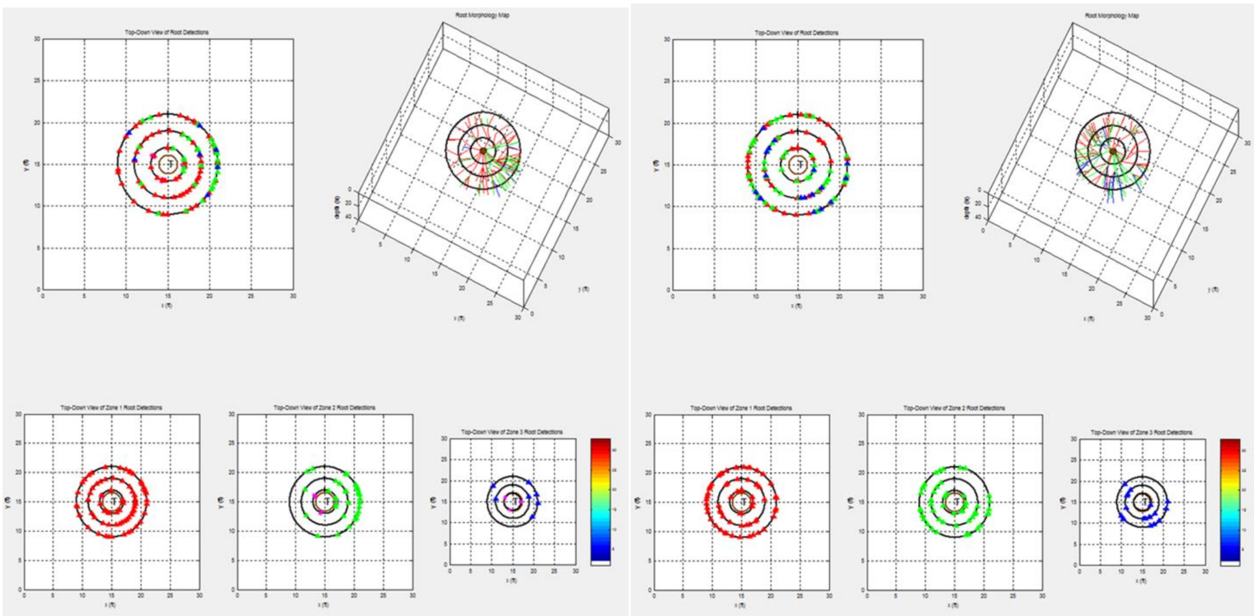


Figure 28 DRI (left) and surface drip control (right) tree 1 top down root detection at different depth zones in the soil from scan 1 (scan date 07/25/2016)

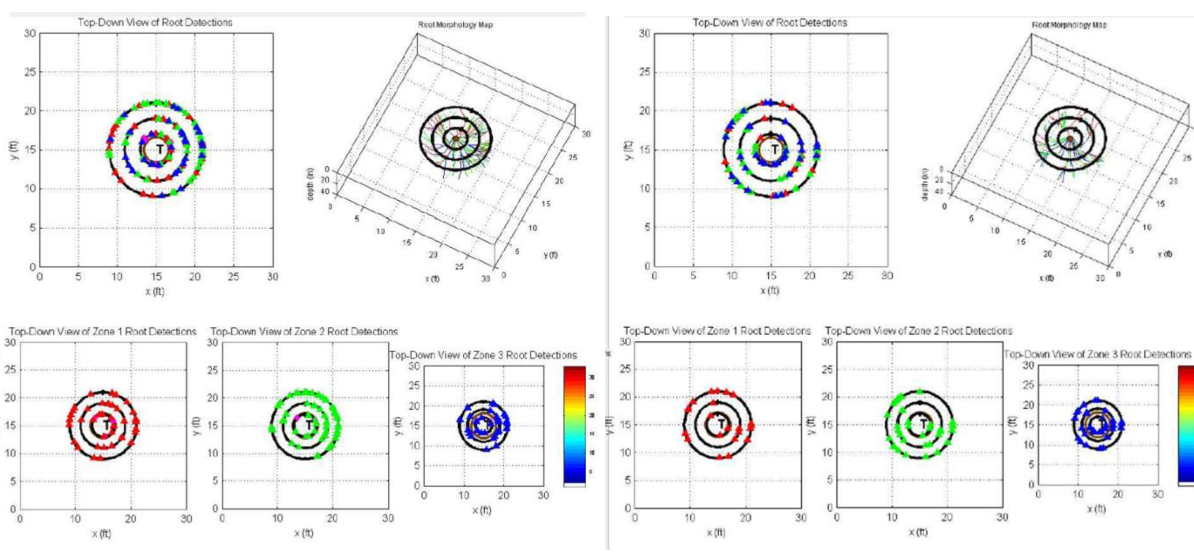


Figure 29 DRI (left) and surface drip control (right) tree 1 top down root detection at different depth zones in the soil from scan 2 (scan date 12/19/2016)

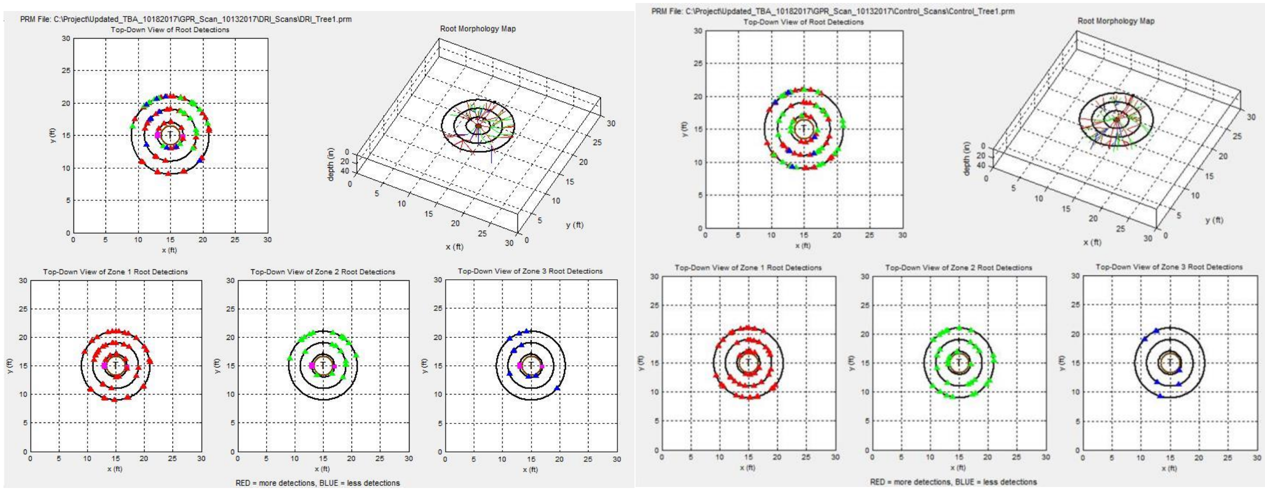


Figure 30 DRI (left) and surface drip control (right) tree 1 top down root detection at different depth zones in the soil from scan 3 (scan date 10/13/2017)

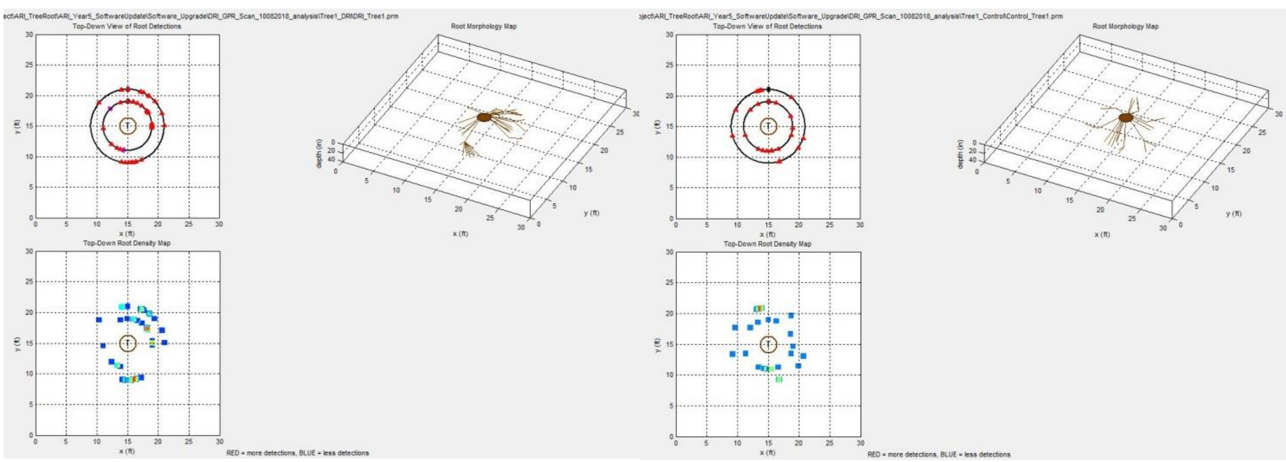


Figure 31 DRI (left) and surface drip control (right) tree 1 top down root detection at different depth zones in the soil from scan 3 (scan date 10/08/2018)

Figures 26 to 29 above represent root maps for both DRI-treated and surface drip irrigated trees for just one tree each. The remainders of the scan results are provided in Appendix C. The fourth scan result looked a bit different because there was a software update and it was difficult to scan the first circle since the tree canopy grew a lot in three years. Using ground penetrating-radar (GPR) scanning throughout the life of the project, the data showed no noticeable difference between DRI-irrigated and surface drip irrigated tree roots. Based on the data collected in this study, there was no evidence to support the theory that the DRI technique may foster stronger vertical root growth providing a better anchor for the plant.

ENERGY SAVINGS COMPARISON:

Water which was delivered from the main pump station situated close to the experimental field provided water to the research field as well as other fields. However, the overall cost of water pumped could be determined so average water costs and energy savings could accurately be attributed to the DRI system. The research area was managed with a single valve to apply water so water volume and pressure was constantly monitored. Data was collected by utilizing a flow meter and pressure transducer.

Before field installation, the DRI equipment was tested in the Center for Irrigation Technology (CIT) hydraulics lab using different pressures to confirm that they would provide the correct flow rate at the same pressure as the surface drip irrigation and as expected by the experimental design. The test results are attached in the Appendix D. From the lab results, emission uniformity for the emitters without DRI unit attached with them was on an average about 98 percent, and with DRI unit attached with them, it was about 91 percent. These values are statistically within an acceptable level but in field conditions it might be different. So, field measurements were done next. The flow rate of the drip emitters and DRI units attached with them in the field was tested by collecting field data and the results are attached in the Appendix D. This uniformity study on the DRI almond block was conducted by Center for Irrigation Technology, senior Agricultural Engineer with help of student research assistants. Field data was collected and analyzed. The analysis results showed a pattern loss of 6.8 percent and an application efficiency of 93.2 percent. Irrigation system pressures can vary throughout the system due to friction loss through pipes, fittings and elevation changes. The loss that causes due to this variation in the irrigation system is defined as irrigation system pattern loss (Santiestiban 2009). Water application efficiency is a measurement of how effective the irrigation system is in storing water in the crop root zone. It is expressed as the percentage of the total volume of water delivered to the field that is stored in the root zone to meet crop evapotranspiration (ET) needs (Irmak et. al. 2011). Active irrigation generally ran from March to October. To calculate the energy savings through water savings, and to compare the DRI and dual-line surface drip control irrigation, the most recent pumping station data was collected.

ESTIMATED ENERGY SAVING FROM WATER SAVING:

The following information was gleaned from the most recent (May, 2012) pump test at the pumping station near the experimental field.

Overall Pumping Efficiency, **OPE**: **49%** (at measured pump condition)
Total Dynamic Head, **TDH** (feet): **189 feet** (at measured pump condition)

kWh/AcFt /Year required for pumping can be calculated using the equation below:

KILOWATT-HOURS REQUIRED TO PUMP PER YEAR FOR IRRIGATION

$$\text{kWh/AcFt} = \frac{1.0241 \times \text{TDH}}{\text{OPE}}$$

$= (1.0241*189)/.49 = 395$ (at measured pump condition)
(Ref: http://www.wateright.net/WWAdvisories/PumpEnergy)

Tree nuts and tree fruits use on an average between 3 and 4 Ac-Ft / acre water/year (according to California Agricultural Production and Irrigated Water Use, Congressional Research Service Report, 2015, pg16 https://fas.org/sgp/crs/misc/R44093.pdf).

In the Fresno State almond orchard, the orchard manager generally applies about 3.5 Ac-Ft/acre/year. We can consider 3.5 Ac-Ft per acre water was applied in the regular surface drip irrigated area in a year in the study plot. So,

Energy use (kWh) per year per acre can be calculated using the equation below:

KILOWATT-HOURS USED PER YEAR FOR IRRIGATION

kWh/Year = AcFt/Year x kWh/AcFt

= 3.5*395=1382.5

According to experimental design, 12.5% less water was applied in the DRI treated area in the first two years of the study. Therefore, about 3.06 Ac-Ft /acre water was applied in a year in the DRI treated area.

Energy use per year per acre can be calculated using the same equation below:

KILOWATT-HOURS USED PER YEAR FOR IRRIGATION

kWh/Year = AcFt/Year x kWh/AcFt

=3.06*395=1208.70

Therefore, Estimated Energy Savings (kWh/year/acre) = 1382.5 – 1208.7 = 173.8

In the third year of the study, 25% less water was applied in the DRI treated area. Therefore, about 2.625 Ac-Ft /acre water was applied in the third year in the DRI treated area.

Energy use per year per acre can be calculated using the same equation below:

KILOWATT-HOURS USED PER YEAR FOR IRRIGATION

kWh/Year = AcFt/Year x kWh/AcFt

=2.625*395=1036.875

Therefore,

Estimated Energy Savings (kWh/year/acre) = 1382.5 – 1036.875=345.63

CONCLUSION AND RECOMMENDATIONS:

DRI is a promising technique of irrigating almond orchards with the potential of up to 25 percent water savings and corresponding energy savings with minor compromises to crop growth and yield especially for the Nonpareil almond variety in the context of reduced availability of irrigation water and risk of fallowing orchards. Four aspects of the study, including soil type, maintenance and sensor issues, sample size and study duration indicate the need for further study.

The study was conducted on one soil type, Hanford sandy loam. Therefore, further studies should be conducted to determine if the DRI technique will perform satisfactorily in other soil types. From a maintenance standpoint, in each growing season, especially after harvest, about 10 percent of the DRI units had to be changed or replaced. Hopefully, this percentage will be reduced under actual field conditions. Monitoring through sap flow sensors was helpful to determine if the plants were under water stress and in the summer of 2016, and part of 2017, some stress was recorded in the DRI trees. Possible causes may have been under -

irrigation and bad data from the sensor. For the most part, this problem was resolved by adjusting irrigation applications as well as more frequent monitoring and maintenance of sensors. This study was conducted on a total of 229 trees, of which 95 trees were irrigated with the DRI technique as the treatment group, and the remaining 134 trees with dual-line surface drip irrigation as the control group and this includes guard trees. The results of this study can be statistically limited by the size of the sample. A larger sample size with more data points would make the study results more reliable. Also, observing the growth and yield after a few more years with less water applied through this new irrigation technique may provide a better indication on its sustainability over time.

Overall, the results of this study indicate as mentioned above that DRI is a promising technique for irrigating almond orchards with the potential of up to 25 percent water savings and corresponding energy savings especially for the Nonpareil almond variety. DRI may help to improve water use efficiency as well. Some site-specific criteria might be applicable such as soil type, weather pattern, management, and maintenance, etc. In the San Joaquin Valley, especially in the summer months (from mid-June to mid-August) when the temperature is very high, closer monitoring of the trees might be necessary to avoid water stress while irrigating at a reduced amount using the DRI technique. Since DRI units are placed underground, and thus prevent water loss that could be caused by evaporation and runoff, other similar techniques of irrigation directly underground such as buried drip emitters may offer similar water and energy saving potential.

REFERENCES

Advanced Pumping Efficiency Program (APEP). 2004. *Flow Meter Brochure*. The Center for Irrigation Technology. June 2004. http://www.pumpefficiency.org/wp-content/uploads/2015/05/APEP06FlowMeterbrochure.pdf

Almond Board of California. 2014. No, Almonds Don't Use 10 Percent of California's Water. http://newsroom.almonds.com/content/no-almonds-don%E2%80%99t-use-10-of-california%E2%80%99s-water

Butnor J.R., Doolittle, J. A., Kress, L., Cohen, S., and Johnson, K.H. 2001. *Use of ground-penetrating radar to study tree roots in the southeastern United States.* Tree Physiology. Vol 21: 1269-1278.

California Almond Acreage Report 2015. California Department of Food and Agriculture and USDA, National Agricultural Statistics Service, Pacific Regional Office. https://www.nass.usda.gov/Statistics_by_State/California/Publications/Fruits_and_Nuts/201605almac.pdf

California Farm Water Coalition. 2015. *Agricultural Water Supplier 2015 Survey: California Agriculture Drought Fact Sheet.* May 2015 (revised 5-26-15). http://farmwater.org/farm-water-news/drought-fact-sheet-may-2015/

Choy, J., and G. McGhee (2014). Groundwater: Ignore It, and It Might Go Away. Understanding California's Groundwater. Published in Water in the West. Retrieved from http://waterinthewest.stanford.edu/groundwater/overview/

Hruska, J., I. Cermak, and S. Sustek. 1997. *Mapping of Tree Root Systems with Ground Penetrating Radar*. Tree Physiology. Vol 19: 125 – 130.

http://www.almonds.com/blog/water/no%20almonds%20don't%20use%2010%20percent%20california's%20water

Irmak, S., Odhiambo, O.O., Kranz, W. L., and Eisenhauer, D. E. 2011. Irrigation Efficiency and Uniformity, and Crop Water Use Efficiency. Biological Systems Engineering: Papers and Publications. 451. https://digitalcommons.unl.edu/biosysengfacpub/451

Johnson, R and Cody, B. 2015. California Agricultural Production and Irrigated Water Use. Retrieved on October 24, 2015 from https://fas.org/sgp/crs/misc/R44093.pdf

LAO. 2008. *California's Water: A Legislative Analyst's Office (LAO) Primer*. October 2008. http://www.lao.ca.gov/2008/rsrc/water_primer/water_primer_102208.pdf

Morris, M. 2006. *Soil Moisture Monitoring: Low-Cost Tools and Methods*. ATTRA - National Sustainable Agriculture Information Service Publication. https://efotg.sc.egov.usda.gov/references/public/NY/ATTRA_SoilMoistureMonitoringTools%26Methods_2006.pdf

NRCS. 2009. *Irrigation Water Management: Small Scale Solutions for Your Farm*. Natural Resources Conservation Service Publication. January 2009. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1167472.pdf

NRCS. 2016. *Web Soil Survey*. 2016 at http://websoilsurvey.sc.egov.usda.gov

Santiesteban, T. G.(2009). Benefits of Pressure Regulation in Irrigation. https://www.irrigation.org/IA/FileUploads/IA/Resources/TechnicalPapers/2009/BenefitsOfPressureRegulationInIrrigation.pdf.

Schwankl, L.J., Prichard, T. L., Hanson, B. R. and Elkins, R. B. (2007). Understanding Your Orchard's Water Requirement. UCANR publication 8212.

University of Florida IFAS Extension. 2007. *Field Guide to Proper Installation, Calibration, and Maintenance of Soil Moisture Sensor Control Systems in Residential Florida Landscapes*. Produced for the St. Johns River Water Management District by The University of Florida Program for Resource Efficient Communities. http://www.swfwmd.state.fl.us/files/database/site_file_sets/13/SMSFieldGuide.pdf

Volder, A. 2016. Exploring the Black Box –Root Growth. UC Davis and Almond Boards of California presentation. Retrieved on 03282017 from http://www.almonds.com/sites/default/files/content/attachments/tree_physiology_how_does_an_almond_tree_grow.pdf

Washington State University Extension. 2013. *Practical Use of Soil Moisture Sensors and Their Data for Irrigation Scheduling Fact Sheet (FS083E).* June 2013. http://cru.cahe.wsu.edu/CEPublications/FS083E/FS083E.pdf

Wateright at Fresno State website at http://www.wateright.net/WWAdvisories/PumpEnergy

APPENDICES

APPENDIX A: WATER DEMAND ESTIMATION TABLES

Table 12: Almond weekly water demand (run time and flow) calculations for May, Year 2017 (ET_0 = in/wk)

Month	**Week**	**Area**	**Shading**	**Shading factor**	**ETo**	**Kc**	**ETc**	**Application Efficiency**	**Required Run Time hr/wk.**	**Design Flow**	**Flow**
		(acre)	%	-	in/wk.	-	in/wk.		hr/wk.	in/wk.	Ac-Ft/wk.
May	1 (1 - 7)	1.9	40	0.81	1.59	0.76	0.98	0.93	61.95	1.30	0.21
May	2 (8 -14)	1.9	40	0.81	1.6	0.76	0.98	0.93	62.34	1.30	0.21
May	3 (15 -21)	1.9	40	0.81	1.71	0.76	1.05	0.93	66.63	1.39	0.22
May	4 (22 - 28)	1.9	40	0.81	1.7	0.76	1.05	0.93	66.24	1.39	0.22
May	5 (29 - 31)	1.9	40	0.81	0.72	0.76	0.44	0.93	28.05	0.59	0.09

Note: Per Calculation, ETc = (ET0)*(Kc)* Shading Factor, Required Run Time (hrs/wk) = ETc/Effective Application Rate (.0158)

Table 13: Almond weekly water demand (run time and flow) calculations for June, Year 2017 (ET_0 = in/wk)

Month	**Week**	**Area**	**Shading**	**Shading factor**	**ETo**	**Kc**	**ETc**	**Application Efficiency**	**Required Run Time hr/wk.**	**Design Flow**	**Flow**
		(acre)	%	-	in/wk.	-	in/wk.		hr/wk.	in/wk.	Ac-Ft/wk.
June	1 (1 - 7)	1.9	40	0.81	2.09	0.76	1.29	0.93	81.43	1.70	0.27
June	2 (8 -14)	1.9	40	0.81	1.84	0.76	1.13	0.93	71.69	1.50	0.24
June	3 (15 -21)	1.9	40	0.81	2.21	0.76	1.36	0.93	86.11	1.80	0.29
June	4 (22 - 28)	1.9	40	0.81	2.13	0.76	1.31	0.93	82.99	1.74	0.28
June	5 (29 - 30)	1.9	40	0.81	0.63	0.76	0.39	0.93	24.55	0.51	0.08

Note: Per Calculation, ETc = (ET0)*(Kc)* Shading Factor, Required Run Time (hrs/wk) = ETc/Effective Application Rate (.0158)

Table 14: Almond weekly water demand (run time and flow) calculations for July, Year 2017 (ET_0 = in/wk)

Month	Week	Area	Shading	Shading factor	ETo	Kc	ETc	Application Efficiency	Required Run Time hr/wk.	Design Flow	Flow
		(acre)	%	-	in/wk.	-	in/wk.		hr/wk.	in/wk.	Ac-Ft/wk.
July	1 (1 - 7)	1.9	40	0.81	2.15	0.76	1.32	0.93	83.77	1.75	0.28
July	2 (8 -14)	1.9	40	0.81	2.09	0.76	1.29	0.93	81.43	1.70	0.27
July	3 (15 -21)	1.9	40	0.81	2.24	0.76	1.38	0.93	87.27	1.83	0.29
July	4 (22 - 28)	1.9	40	0.81	2.07	0.76	1.27	0.93	80.65	1.69	0.27
July	5 (29 - 30)	1.9	40	0.81	0.95	0.76	0.58	0.93	37.01	0.77	0.12

Note: Per Calculation, ETc = (ET0)*(Kc)* Shading Factor, Required Run Time (hrs/wk) = ETc/Effective Application Rate (.0158)

Table 15: Almond weekly water demand (run time and flow) calculations for August, Year 2017 (ET_0 = in/wk)

Month	Week	Area	Shading	Shading factor	ETo	Kc	ETc	Application Efficiency	Required Run Time hr/wk.	Design Flow	Flow
		(acre)	%	-	in/wk	-	in/wk.		hr/wk.	in/wk.	Ac-Ft/wk.
Aug	1 (1 - 7)	1.9	40	0.81	1.79	0.76	1.10	0.93	69.74	1.46	0.23
Aug	2 (8 -14)	1.9	40	0.81	1.98	0.76	1.22	0.93	77.14	1.61	0.26
Aug	3 (15 -21)	1.9	40	0.81	1.68	0.76	1.03	0.93	65.46	1.37	0.22
Aug	4 (22 - 28)	1.9	40	0.81	1.81	0.76	1.11	0.93	70.52	1.48	0.23
Aug	5 (29 - 30)	1.9	40	0.81	0.8	0.76	0.49	0.93	31.17	0.65	0.10

Note: Per Calculation, ETc = (ET0)*(Kc)* Shading Factor, Required Run Time (hrs/wk) = ETc/Effective Application Rate (.0158)

Table 16: Almond weekly water demand (run time and flow) calculations for September, Year 2017 (ET_0 = in/wk.)

Month	Week	Area	Shading	Shading factor	ETo	Kc	ETc	Application Efficiency	Required Run Time hr/wk.	Design Flow	Flow
		(acre)	%	-	in/wk.	-	in/wk.		hr/wk.	in/wk.	Ac-Ft/wk.
Sep	1 (1 - 7)	1.9	40	0.81	1.6	0.76	0.98	0.93	62.34	1.30	0.21
Sep	2 (8 -14)	1.9	40	0.81	1.36	0.76	0.84	0.93	52.99	1.11	0.18
Sep	3 (15 -21)	1.9	40	0.81	1.38	0.76	0.85	0.93	53.77	1.13	0.18
Sep	4 (22 - 28	1.9	40	0.81	1.21	0.76	0.74	0.93	47.14	0.99	0.16
Sep	5 (29 - 30	1.9	40	0.81	0.39	0.76	0.24	0.93	15.20	0.32	0.05

Note: Per Calculation, ETc = (ET0)*(Kc)* Shading Factor, Required Run Time (hrs/wk) = ETc/Effective Application Rate (.0158)

Table 17: Almond weekly water demand (run time and flow) calculations for July, Year 2018 (ET_0 = in/wk)

Month	Week	Area	Shading	Shading factor	ETo	Kc	ETc	Application Efficiency	Required Run Time hr/wk.	Design Flow	Flow
		(acre)	%	-	in/wk.	-	in/wk.		hr/wk.	in/wk.	Ac-Ft/wk.
July	1 (1 - 7)	1.9	40	0.81	2.09	0.85	1.44	0.93	91.07	1.91	0.30
July	2 (8 - 14)	1.9	40	0.81	2.15	0.85	1.48	0.93	93.69	1.96	0.31
July	3 (15 - 21	1.9	40	0.81	2.13	0.85	1.47	0.93	92.82	1.94	0.31
July	4 (22 - 28	1.9	40	0.81	2.07	0.85	1.43	0.93	90.20	1.89	0.30
July	5 (29 -30)	1.9	40	0.81	0.83	0.85	0.57	0.93	36.17	0.76	0.12

Note: Per Calculation, ETc = (ET0)*(Kc)* Shading Factor, Required Run Time (hrs/wk) = ETc/Effective Application Rate (.0158)

Table 18: Almond weekly water demand (run time and flow) calculations for August, Year 2018 (ET_0 = in/wk)

Month	Week	Area	Shading	Shading factor	ETo	Kc	ETc	Application Efficiency	Required Run Time hr/wk.	Design Flow	Flow
		(acre)	%	-	in/wk.	-	in/wk.		hr/wk.	in/wk.	Ac-Ft/wk.
August	1 (1 - 7)	1.9	40	0.81	2.06	0.85	1.42	0.93	89.77	1.88	0.30
August	2 (8 - 14)	1.9	40	0.81	1.87	0.85	1.29	0.93	81.49	1.71	0.27
August	3 (15 - 21)	1.9	40	0.81	1.91	0.85	1.32	0.93	83.23	1.74	0.28
August	4 (22 - 28)	1.9	40	0.81	1.68	0.85	1.16	0.93	73.21	1.53	0.24
August	5 (29 -31)	1.9	40	0.81	0.68	0.85	0.47	0.93	29.63	0.62	0.10

Note: Per Calculation, ETc = (ET0)*(Kc)* Shading Factor, Required Run Time (hrs/wk) = ETc/Effective Application Rate (.0158)

Table 19: Almond weekly water demand (run time and flow) calculations for August, Year 2018 (ET_0 = in/wk)

Month	Week	Area	Shading	Shading factor	ETo	Kc	ETc	Application Efficiency	Required Run Time hr/wk.	Design Flow	Flow
		(acre)	%	-		-	in/wk.		hr/wk.	in/wk.	Ac-Ft/wk.
Sept	1 (1 - 7)	1.9	40	0.81	1.65	0.85	1.14	0.93	71.90	1.50	0.24
Sept	2 (8 - 14)	1.9	40	0.81	1.57	0.85	1.08	0.93	68.41	1.43	0.23
Sept	3 (15 - 21	1.9	40	0.81	1.42	0.85	0.98	0.93	61.88	1.30	0.21
Sept	4 (22 - 28	1.9	40	0.81	1.34	0.85	0.92	0.93	58.39	1.22	0.19
Sept	5 (29 -31)	1.9	40	0.81	0.29	0.85	0.20	0.93	12.64	0.26	0.04

Note: Per Calculation, ETc = (ET0)*(Kc)* Shading Factor, Required Run Time (hrs/wk) = ETc/Effective Application Rate (.0158)

Appendix B: Crop Growth Statistical Analysis

```
T-TEST PAIRS=All_NP_Girth_DRI WITH All_NP_Girth_Control (PAIRED)
  /CRITERIA=CI(.9500)
  /MISSING=ANALYSIS.
```

T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	All_NP_Girth_DRI	14.0126	54	2.59205	.35273
	All_NP_Girth_Control	14.2865	54	2.61224	.35548

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	All_NP_Girth_DRI & All_NP_Girth_Control	54	.950	.000

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	All_NP_Girth_DRI - All_NP_Girth_Control	-.27389	.82304	.11200	-.49854	-.04924	-2.445	53	.018

Note: Sig(2 tailed) value >.05 means there is no difference between the two groups

Figure 32: Nonpareil variety trunk girth comparison statistical analysis result

```
T-TEST PAIRS=All_SP_Height_DRI WITH All_SP_Height_Control (PAIRED)
  /CRITERIA=CI(.9500)
  /MISSING=ANALYSIS.
```

T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	All_SP_Height_DRI	10.6000	54	2.19442	.29862
	All_SP_Height_Control	11.1370	54	2.25751	.30721

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	All_SP_Height_DRI & All_SP_Height_Control	54	.920	.000

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	All_SP_Height_DRI - All_SP_Height_Control	-.53704	.89365	.12161	-.78096	-.29312	-4.416	53	.000

Note: Sig(2 tailed) value >.05 means there is no difference between the two groups

Figure 33: Supareil variety tree height comparison statistical analysis result

```
T-TEST PAIRS=All_SP_Girth_DRI WITH All_SP_Girth_Control (PAIRED)
  /CRITERIA=CI(.9500)
  /MISSING=ANALYSIS.
```

T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	All_SP_Girth_DRI	14.2402	54	2.79225	.37998
	All_SP_Girth_Control	14.8498	54	2.90801	.39573

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	All_SP_Girth_DRI & All_SP_Girth_Control	54	.923	.000

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	All_SP_Girth_DRI - All_SP_Girth_Control	-.60963	1.12368	.15291	-.91634	-.30292	-3.987	53	.000

Note: Sig(2 tailed) value >.05 means there is no difference between the two groups

Figure 34: Supareil variety trunk girth comparison statistical analysis result

```
T-TEST PAIRS=Fruit_SP_DRI WITH Fruit_SP_Control (PAIRED)
  /CRITERIA=CI(.9500)
  /MISSING=ANALYSIS.
```

T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Fruit_SP_DRI	2.7460	63	3.75013	.47247
	Fruit_SP_Control	2.8095	63	3.66261	.46145

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Fruit_SP_DRI & Fruit_SP_Control	63	.440	.000

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Fruit_SP_DRI - Fruit_SP_Control	-.06349	3.92212	.49414	-1.05126	.92428	-.128	62	.898

Note: Sig(2 tailed) value >.05 means there is no difference between the two groups

Figure 35: Supareil variety fruit setting comparison statistical analysis result

```
T-TEST PAIRS=Leaf_SP_DRI WITH Leaf_SP_Control (PAIRED)
  /CRITERIA=CI(.9500)
  /MISSING=ANALYSIS.
```

T-Test

[DataSet1] C:\Project\DRI\Crop_Growth_Status_Data\Statistical_Analysis\Crop_Growth_paired_t_test_result.sav

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Leaf_SP_DRI	21.2222	63	4.18309	.52702
	Leaf_SP_Control	21.4762	63	3.26693	.41159

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Leaf_SP_DRI & Leaf_SP_Control	63	.011	.932

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Leaf_SP_DRI - Leaf_SP_Control	-.25397	5.27920	.66512	-1.58352	1.07558	-.382	62	.704

Figure 36: Supareil variety leaf setting comparison statistical analysis result

Appendix C: GPR Root Mapping

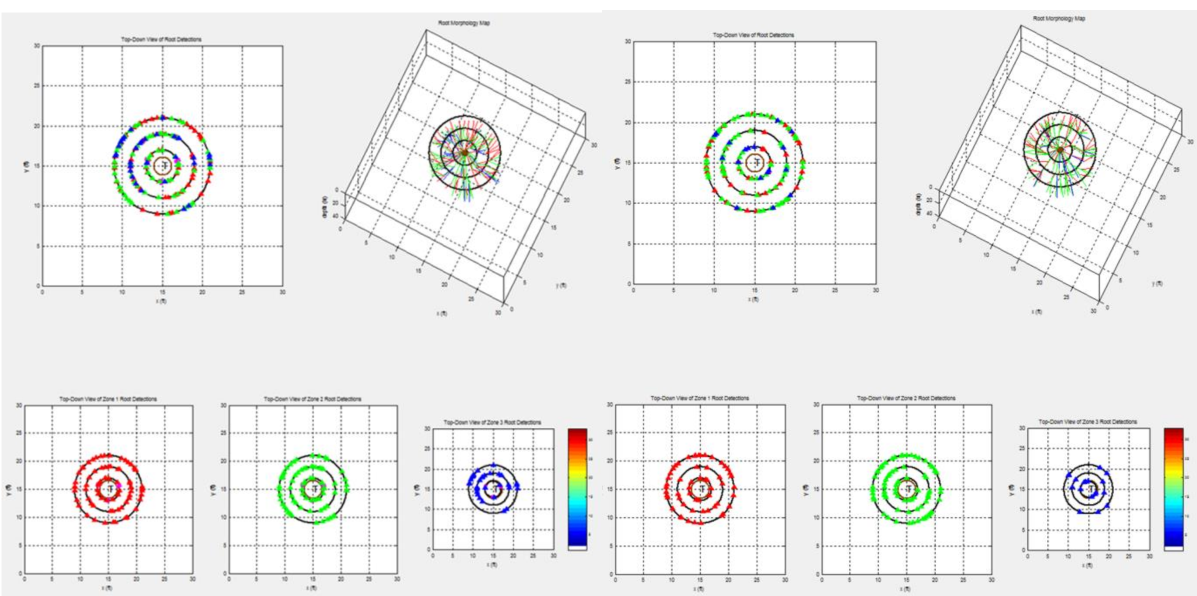


Figure 37: DRI (left) and surface drip control (right) tree 2 top down root detection at different depth zones in the soil from scan 1 (scan date 07/25/2016)

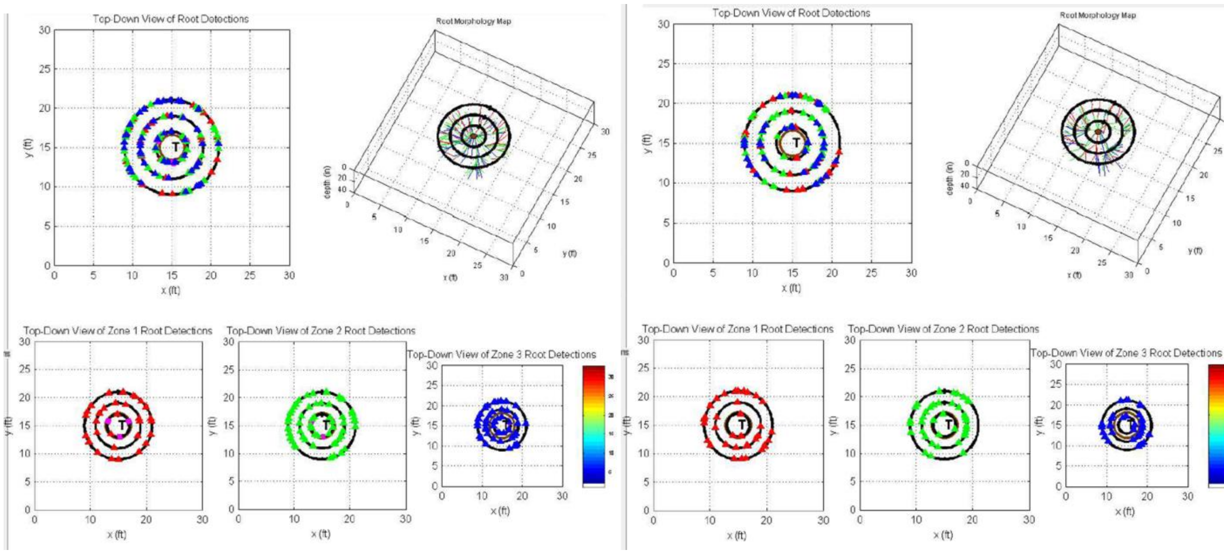


Figure 38: DRI (left) and surface drip control (right) tree 2 top down root detection at different depth zones in the soil from scan 2 (scan date 12/19/2016)

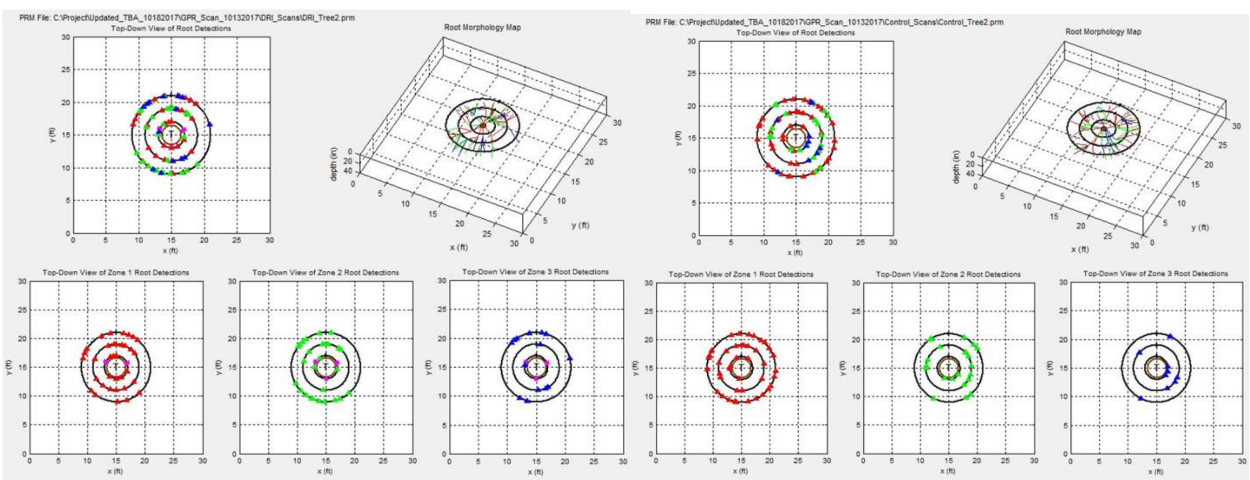


Figure 39: DRI (left) and surface drip control (right) tree 2 top down root detection at different depth zones in the soil from scan 3 (scan date 10/13/2017)

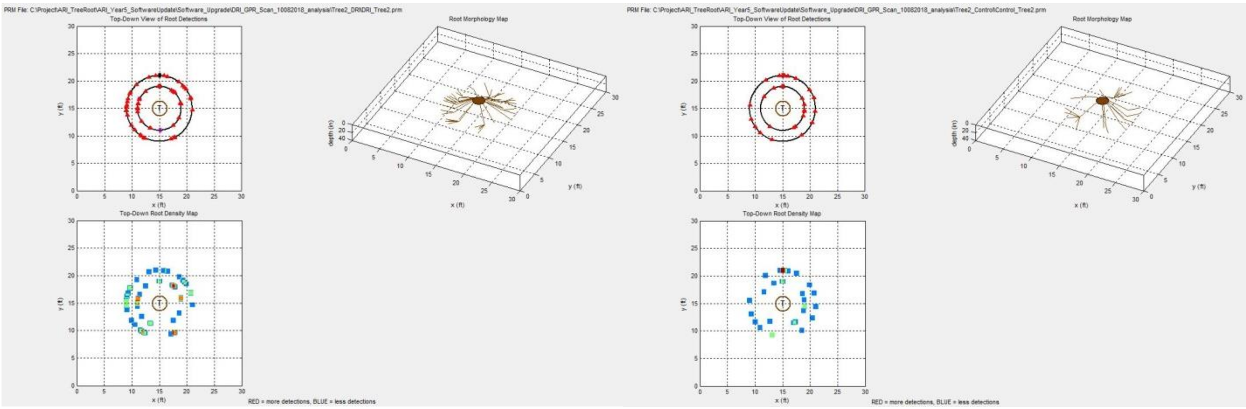


Figure 40: DRI (left) and surface drip control (right) tree 2 top down root detection at different depth zones in the soil from scan 4 (scan date 10/08/2018)

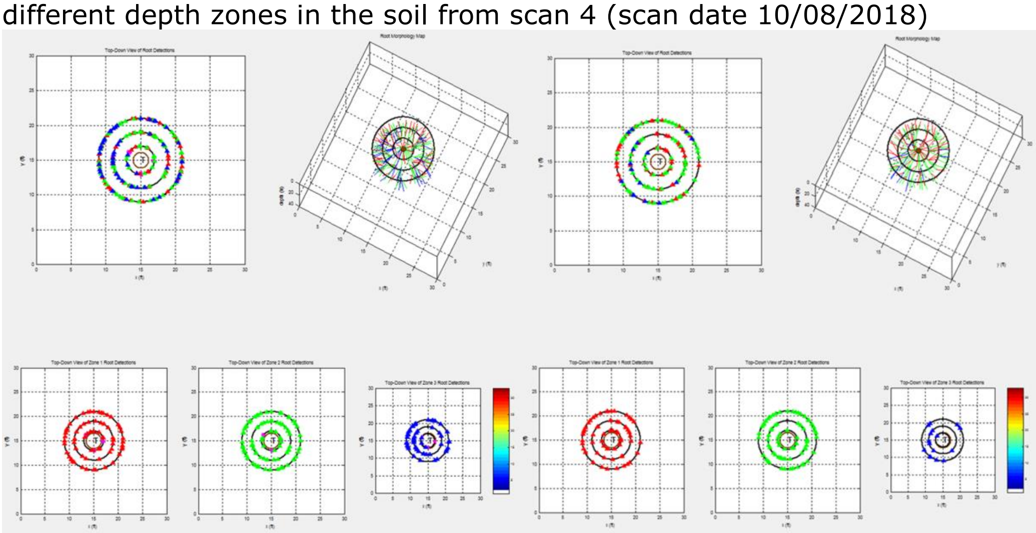


Figure 41: DRI (left) and surface drip control (right) tree 3 top down root detection at different depth zones in the soil from scan 1 (scan date 07/25/2016)

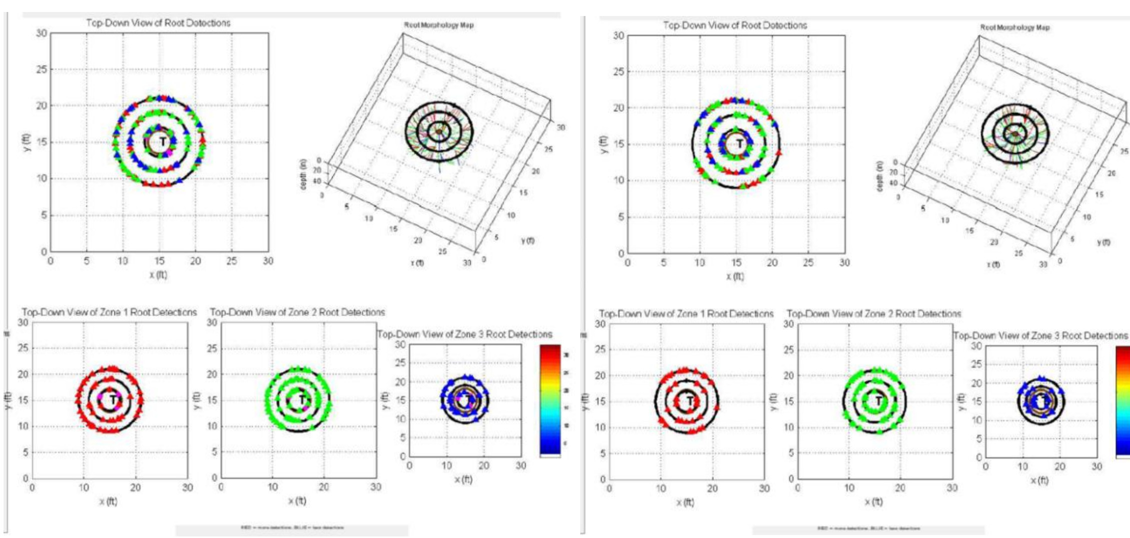


Figure 42: DRI (left) and surface drip control (right) tree 3 top down root detection at different depth zones in the soil from scan 2 (scan date 12/19/2016)

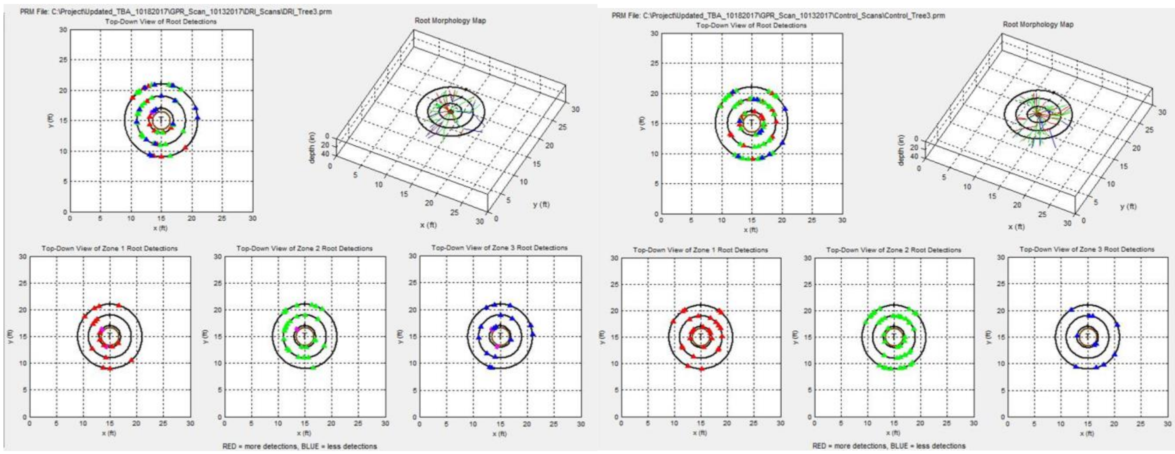


Figure 43: DRI (left) and surface drip control (right) tree 3 top down root detection at different depth zones in the soil from scan 3 (scan date 10/13/2017)

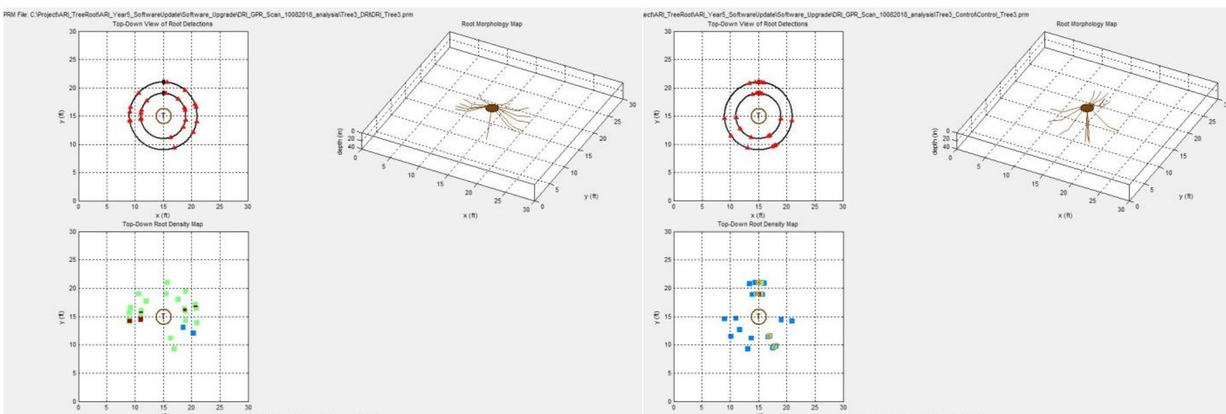


Figure 44: DRI (left) and surface drip control (right) tree 3 top down root detection at different depth zones in the soil from scan 3 (scan date 10/08/2018)

APPENDIX D: LAB TESTING OF EQUIPMENT

The test results are attached here

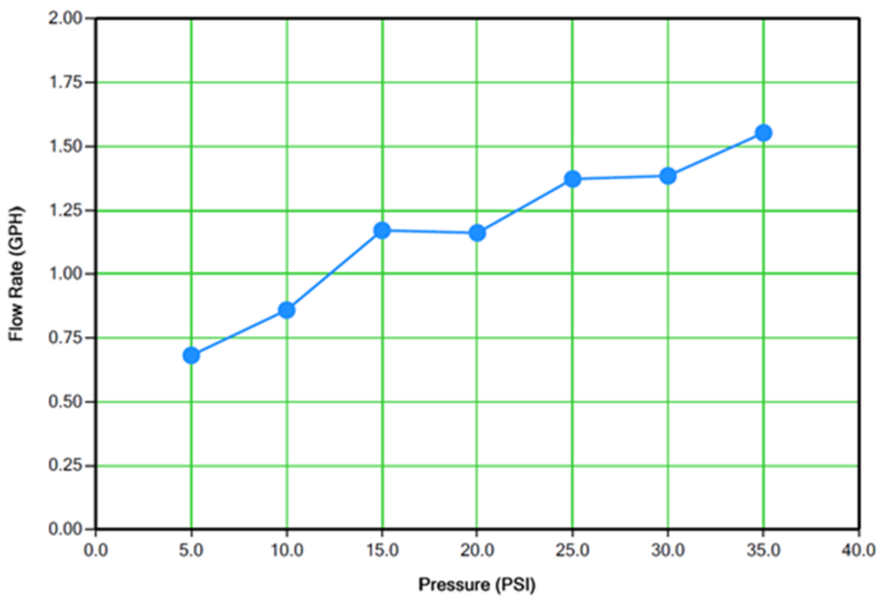
FRESNO STATE
Center for Irrigation Technology

5370 N Chestnut Ave M/S OF18
Fresno, CA 93740-8021
559.278.2066 FAX 559.278.6033
www.californiawater.org()

FRESNO STATE
International Center
for Water Technology

Emitter Description	: DRI - Netafim Black Emitters
Manufacturer	: Netafim
Supplier	: Tim Jacobsen_DRI
Test Date	: 04/20/16
Number Tested	: 25

Pressure (PSI)	Temp (°F)	Mean Flow (GPH)	Std. Dev. (GPH)	Mfg's Cv	EU (%)	CU (%)	Emitter Constant	Emitter Exponent
5.0	71.8	0.682	0.01	0.015	98	99		
10.0	73.0	0.860	0.01	0.014	98	99	0.288	0.476
15.0	76.1	1.172	0.02	0.013	99	99	0.341	0.456
20.0	77.5	1.162	0.02	0.013	99	99	0.482	0.293
25.0	78.4	1.373	0.02	0.017	98	99	0.328	0.445
30.0	79.0	1.385	0.02	0.013	99	99	0.410	0.358
35.0	79.5	1.553	0.02	0.015	99	99		



Emitter Description : DRI - Netafim Black Emitters
Manufacturer : Netafim
Supplier : Tim Jacobsen_DRI

Test Date	# Tested	Mean Flow	Test Pressure	Test Temperature	Duration
04/20/16	25	0.68 GPH 2.58 LPH	5.0 PSI 34.5 kPa	72 (°F) 22 (°C)	10.0 Min.

Standard Deviation	: 0.010 (gph) 0.039 (lph)	**† Emission Uniformity**	: 98 %
Coefficient of Mfg. Variability	: 0.015	**‡ Uniformity Coefficient**	: 99 %

* Test Data

Emitter Number	mL	gph	Lph
1	420.00	0.67	2.52
2	420.00	0.67	2.52
3	422.00	0.67	2.53
4	424.00	0.67	2.54
5	424.00	0.67	2.54
6	426.00	0.68	2.56
7	426.00	0.68	2.56
8	426.00	0.68	2.56
9	426.00	0.68	2.56
10	428.00	0.68	2.57
11	428.00	0.68	2.57
12	430.00	0.68	2.58
13	430.00	0.68	2.58
14	430.00	0.68	2.58
15	431.00	0.68	2.59
16	432.00	0.68	2.59
17	434.00	0.69	2.60
18	434.00	0.69	2.60
19	438.00	0.69	2.63
20	438.00	0.69	2.63
21	438.00	0.69	2.63
22	438.00	0.69	2.63
23	440.00	0.70	2.64
24	440.00	0.70	2.64
25	442.00	0.70	2.65

* Data is sorted in ascending order.

† Emission Uniformity = 100(L/M)

Where: L = Mean flow of the lowest flowing 25% of the emitters
M = Mean flow rate

‡ Uniformity Coefficient = 100(1-D/M)

Where: D = Average absolute deviation from the mean flow rate
M = Mean flow rate

Emitter Description : DRI - Netafim Black Emitters
Manufacturer : Netafim
Supplier : Tim Jacobsen_DRI

Test Date	# Tested	Mean Flow	Test Pressure	Test Temperature	Duration
04/20/16	25	0.86 GPH 3.25 LPH	10.0 PSI 68.9 kPa	73 (°F) 23 (°C)	8.0 Min.

Standard Deviation	: 0.012 (gph) 0.046 (lph)	**† Emission Uniformity**	: 98 %
Coefficient of Mfg. Variability	: 0.014	**‡ Uniformity Coefficient**	: 99 %

* Test Data

Emitter Number	mL	gph	Lph
1	422.00	0.84	3.17
2	426.00	0.84	3.20
3	426.00	0.84	3.20
4	426.00	0.84	3.20
5	428.00	0.85	3.21
6	428.00	0.85	3.21
7	428.00	0.85	3.21
8	430.00	0.85	3.23
9	432.00	0.86	3.24
10	432.00	0.86	3.24
11	434.00	0.86	3.26
12	434.00	0.86	3.26
13	436.00	0.86	3.27
14	436.00	0.86	3.27
15	436.00	0.86	3.27
16	436.00	0.86	3.27
17	438.00	0.87	3.29
18	438.00	0.87	3.29
19	438.00	0.87	3.29
20	440.00	0.87	3.30
21	440.00	0.87	3.30
22	442.00	0.88	3.32
23	442.00	0.88	3.32
24	442.00	0.88	3.32
25	444.00	0.88	3.33

* Data is sorted in ascending order.

† Emission Uniformity = 100(L/M)

Where: L = Mean flow of the lowest flowing 25% of the emitters
M = Mean flow rate

‡ Uniformity Coefficient = 100(1-D/M)

Where: D = Average absolute deviation from the mean flow rate
M = Mean flow rate

Emitter Description : DRI - Netafim Black Emitters
Manufacturer : Netafim
Supplier : Tim Jacobsen_DRI

Test Date	# Tested	Mean Flow	Test Pressure	Test Temperature	Duration
04/20/16	25	1.17 GPH 4.44 LPH	15.0 PSI 103.4 kPa	76 (°F) 24 (°C)	6.0 Min.

Standard Deviation	: 0.016 (gph) 0.060 (lph)	**† Emission Uniformity**	: 99 %
Coefficient of Mfg. Variability	: 0.013	**‡ Uniformity Coefficient**	: 99 %

* Test Data

Emitter Number	mL	gph	Lph
1	438.00	1.16	4.38
2	438.00	1.16	4.38
3	438.00	1.16	4.38
4	438.00	1.16	4.38
5	438.00	1.16	4.38
6	440.00	1.16	4.40
7	440.00	1.16	4.40
8	440.00	1.16	4.40
9	440.00	1.16	4.40
10	440.00	1.16	4.40
11	440.00	1.16	4.40
12	440.00	1.16	4.40
13	442.00	1.17	4.42
14	442.00	1.17	4.42
15	442.00	1.17	4.42
16	444.00	1.17	4.44
17	444.00	1.17	4.44
18	447.00	1.18	4.47
19	448.00	1.18	4.48
20	450.00	1.19	4.50
21	452.00	1.19	4.52
22	452.00	1.19	4.52
23	452.00	1.19	4.52
24	454.00	1.20	4.54
25	458.00	1.21	4.58

* Data is sorted in ascending order.

† Emission Uniformity = 100(L/M)

Where: L = Mean flow of the lowest flowing 25% of the emitters
M = Mean flow rate

‡ Uniformity Coefficient = 100(1-D/M)

Where: D = Average absolute deviation from the mean flow rate
M = Mean flow rate

Emitter Description : DRI - Netafim Black Emitters
Manufacturer : Netafim
Supplier : Tim Jacobsen_DRI

Test Date	# Tested	Mean Flow	Test Pressure	Test Temperature	Duration
04/20/16	25	1.16 GPH 4.40 LPH	20.0 PSI 137.8 kPa	78 (°F) 25 (°C)	6.0 Min.

Standard Deviation	: 0.015 (gph) 0.058 (lph)	**† Emission Uniformity**	: 99 %
Coefficient of Mfg. Variability	: 0.013	**‡ Uniformity Coefficient**	: 99 %

* Test Data

Emitter Number	mL	gph	Lph
1	432.00	1.14	4.32
2	432.00	1.14	4.32
3	434.00	1.15	4.34
4	434.00	1.15	4.34
5	434.00	1.15	4.34
6	436.00	1.15	4.36
7	436.00	1.15	4.36
8	438.00	1.16	4.38
9	438.00	1.16	4.38
10	438.00	1.16	4.38
11	438.00	1.16	4.38
12	438.00	1.16	4.38
13	438.00	1.16	4.38
14	438.00	1.16	4.38
15	440.00	1.16	4.40
16	440.00	1.16	4.40
17	440.00	1.16	4.40
18	442.00	1.17	4.42
19	442.00	1.17	4.42
20	444.00	1.17	4.44
21	446.00	1.18	4.46
22	448.00	1.18	4.48
23	450.00	1.19	4.50
24	450.00	1.19	4.50
25	454.00	1.20	4.54

* Data is sorted in ascending order.

† Emission Uniformity = 100(L/M)

Where: L = Mean flow of the lowest flowing 25% of the emitters
M = Mean flow rate

‡ Uniformity Coefficient = 100(1-D/M)

Where: D = Average absolute deviation from the mean flow rate
M = Mean flow rate

Emitter Description : DRI - Netafim Black Emitters
Manufacturer : Netafim
Supplier : Tim Jacobsen_DRI

Test Date	# Tested	Mean Flow	Test Pressure	Test Temperature	Duration
04/20/16	25	1.37 GPH 5.20 LPH	25.0 PSI 172.3 kPa	78 (°F) 26 (°C)	5.0 Min.

Standard Deviation : 0.023 (gph) 0.086 (lph)
Coefficient of Mfg. Variability : 0.017

† Emission Uniformity : 98 %
‡ Uniformity Coefficient : 99 %

* Test Data

Emitter Number	mL	gph	Lph
1	420.00	1.33	5.04
2	423.00	1.34	5.08
3	424.00	1.34	5.09
4	426.00	1.35	5.11
5	428.00	1.36	5.14
6	428.00	1.36	5.14
7	428.00	1.36	5.14
8	430.00	1.36	5.16
9	430.00	1.36	5.16
10	430.00	1.36	5.16
11	430.00	1.36	5.16
12	430.00	1.36	5.16
13	432.00	1.37	5.18
14	432.00	1.37	5.18
15	432.00	1.37	5.18
16	434.00	1.38	5.21
17	438.00	1.39	5.26
18	438.00	1.39	5.26
19	440.00	1.39	5.28
20	440.00	1.39	5.28
21	442.00	1.40	5.30
22	442.00	1.40	5.30
23	444.00	1.41	5.33
24	444.00	1.41	5.33
25	446.00	1.41	5.35

* Data is sorted in ascending order.

† Emission Uniformity = 100(L/M)

Where: L = Mean flow of the lowest flowing 25% of the emitters
M = Mean flow rate

‡ Uniformity Coefficient = 100(1-D/M)

Where: D = Average absolute deviation from the mean flow rate
M = Mean flow rate

Emitter Description : DRI - Netafim Black Emitters
Manufacturer : Netafim
Supplier : Tim Jacobsen_DRI

Test Date	# Tested	Mean Flow	Test Pressure	Test Temperature	Duration
04/20/16	25	1.38 GPH 5.24 LPH	30.0 PSI 206.8 kPa	79 (°F) 26 (°C)	5.0 Min.

Standard Deviation	: 0.018 (gph) 0.067 (lph)	**† Emission Uniformity**	: 99 %
Coefficient of Mfg. Variability	: 0.013	**‡ Uniformity Coefficient**	: 99 %

* Test Data

Emitter Number	mL	gph	Lph
1	428.00	1.36	5.14
2	430.00	1.36	5.16
3	432.00	1.37	5.18
4	432.00	1.37	5.18
5	432.00	1.37	5.18
6	432.00	1.37	5.18
7	432.00	1.37	5.18
8	434.00	1.38	5.21
9	434.00	1.38	5.21
10	434.00	1.38	5.21
11	436.00	1.38	5.23
12	436.00	1.38	5.23
13	436.00	1.38	5.23
14	436.00	1.38	5.23
15	436.00	1.38	5.23
16	438.00	1.39	5.26
17	438.00	1.39	5.26
18	440.00	1.39	5.28
19	440.00	1.39	5.28
20	442.00	1.40	5.30
21	442.00	1.40	5.30
22	446.00	1.41	5.35
23	446.00	1.41	5.35
24	448.00	1.42	5.38
25	448.00	1.42	5.38

* Data is sorted in ascending order.

† Emission Uniformity = 100(L/M)

Where: L = Mean flow of the lowest flowing 25% of the emitters
M = Mean flow rate

‡ Uniformity Coefficient = 100(1-D/M)

Where: D = Average absolute deviation from the mean flow rate
M = Mean flow rate

Emitter Description : DRI - Netafim Black Emitters
Manufacturer : Netafim
Supplier : Tim Jacobsen_DRI

Test Date	# Tested	Mean Flow	Test Pressure	Test Temperature	Duration
04/20/16	25	1.55 GPH 5.88 LPH	35.0 PSI 241.2 kPa	80 (°F) 26 (°C)	4.5 Min.

Standard Deviation	: 0.023 (gph) 0.087 (lph)	**† Emission Uniformity**	: 99 %
Coefficient of Mfg. Variability	: 0.015	**‡ Uniformity Coefficient**	: 99 %

* Test Data

Emitter Number	mL	gph	Lph
1	430.00	1.51	5.73
2	434.00	1.53	5.79
3	434.00	1.53	5.79
4	436.00	1.54	5.81
5	436.00	1.54	5.81
6	438.00	1.54	5.84
7	438.00	1.54	5.84
8	438.00	1.54	5.84
9	438.00	1.54	5.84
10	438.00	1.54	5.84
11	438.00	1.54	5.84
12	440.00	1.55	5.87
13	440.00	1.55	5.87
14	440.00	1.55	5.87
15	440.00	1.55	5.87
16	440.00	1.55	5.87
17	442.00	1.56	5.89
18	442.00	1.56	5.89
19	444.00	1.56	5.92
20	446.00	1.57	5.95
21	448.00	1.58	5.97
22	450.00	1.59	6.00
23	450.00	1.59	6.00
24	454.00	1.60	6.05
25	458.00	1.61	6.11

* Data is sorted in ascending order.

† Emission Uniformity = 100(L/M)

Where: L = Mean flow of the lowest flowing 25% of the emitters
M = Mean flow rate

‡ Uniformity Coefficient = 100(1-D/M)

Where: D = Average absolute deviation from the mean flow rate
M = Mean flow rate

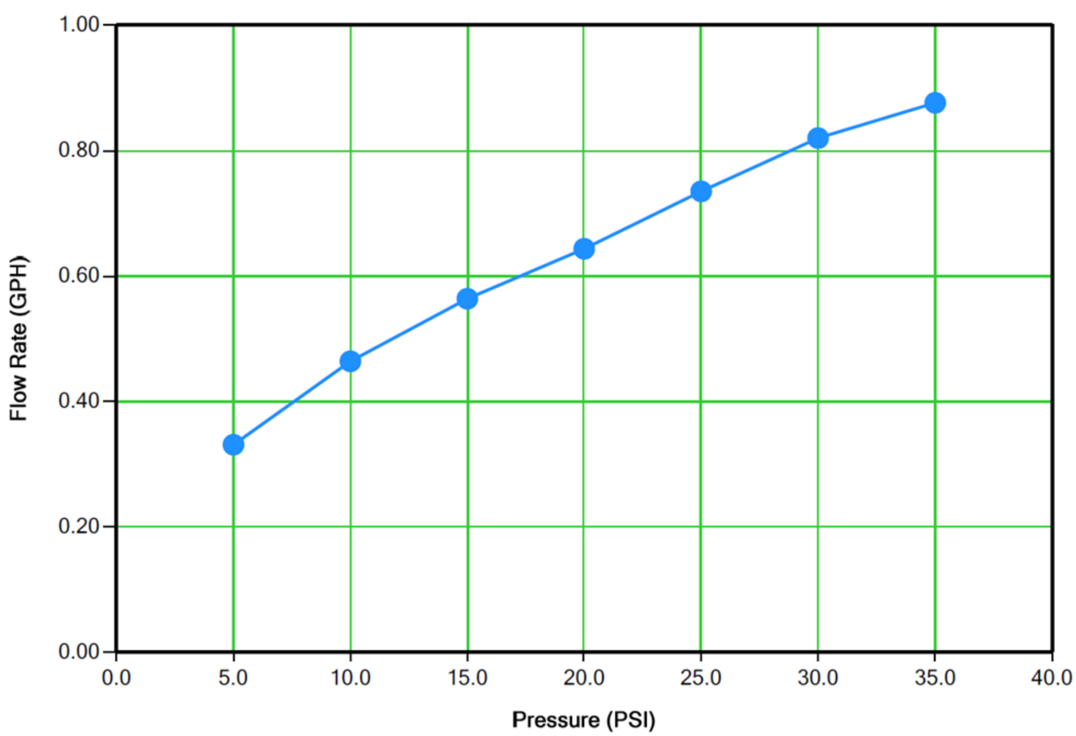
FRESNO STATE
Center for Irrigation Technology

5370 N Chestnut Ave M/S OF18
Fresno, CA 93740-8021
559.278.2066 FAX 559.278.6033
www.californiawater.org()

FRESNO STATE
International Center
for Water Technology

Emitter Description	: DRI_0.5gph
Manufacturer	: DRI
Supplier	: DRI
Test Date	: 04/25/16
Number Tested	: 25

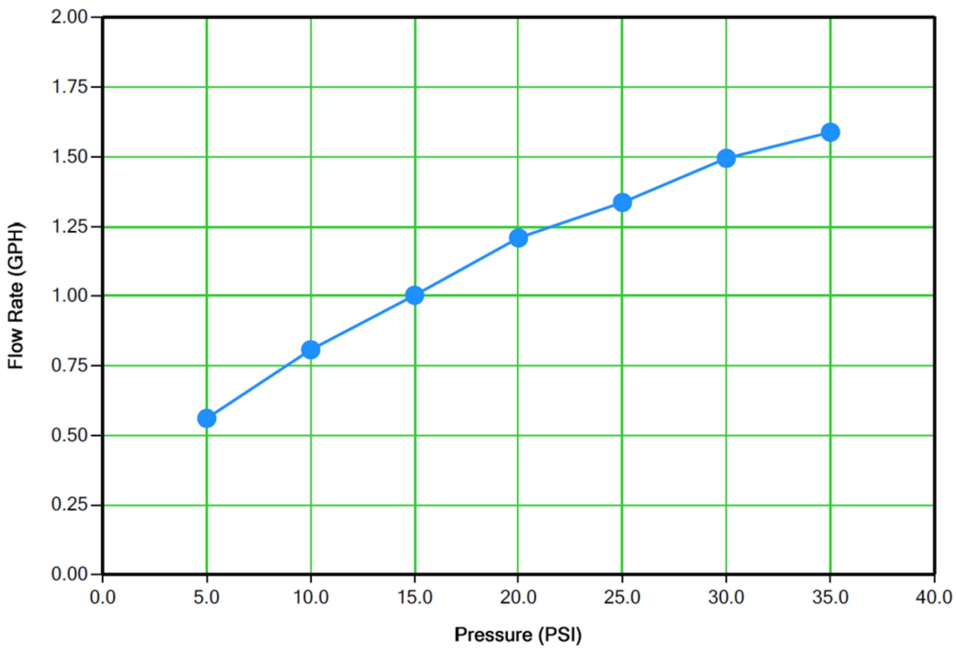
Pressure (PSI)	Temp (°F)	Mean Flow (GPH)	Std. Dev. (GPH)	Mfg's Cv	EU (%)	CU (%)	Emitter Constant	Emitter Exponent
5.0	65.7	0.331	0.04	0.126	84	90		
10.0	66.2	0.464	0.06	0.130	83	89	0.152	0.485
15.0	66.6	0.564	0.06	0.106	86	91	0.157	0.472
20.0	73.6	0.644	0.08	0.118	84	91	0.137	0.516
25.0	74.1	0.735	0.10	0.130	82	90	0.108	0.597
30.0	75.6	0.820	0.10	0.126	82	90	0.138	0.524
35.0	76.5	0.876	0.10	0.117	84	90		



FRESNO STATE Center for Irrigation Technology
5370 N Chestnut Ave M/S OF18
Fresno, CA 93740-8021
559.278.2066 FAX 559.278.6033
www.californiawater.org()
FRESNO STATE International Center for Water Technology

Emitter Description	: DRI_1gph
Manufacturer	: DRI
Supplier	: DRI
Test Date	: 04/21/16
Number Tested	: 25

Pressure (PSI)	Temp (°F)	Mean Flow (GPH)	Std. Dev. (GPH)	Mfg's Cv	EU (%)	CU (%)	Emitter Constant	Emitter Exponent
5.0	75.9	0.561	0.03	0.057	92	95		
10.0	78.3	0.808	0.04	0.055	92	96	0.239	0.529
15.0	78.6	1.004	0.06	0.062	91	95	0.209	0.580
20.0	78.4	1.210	0.09	0.075	90	94	0.222	0.565
25.0	71.8	1.337	0.13	0.095	87	92	0.251	0.520
30.0	72.3	1.495	0.13	0.089	89	93	0.259	0.516
35.0	73.4	1.589	0.13	0.084	89	93		



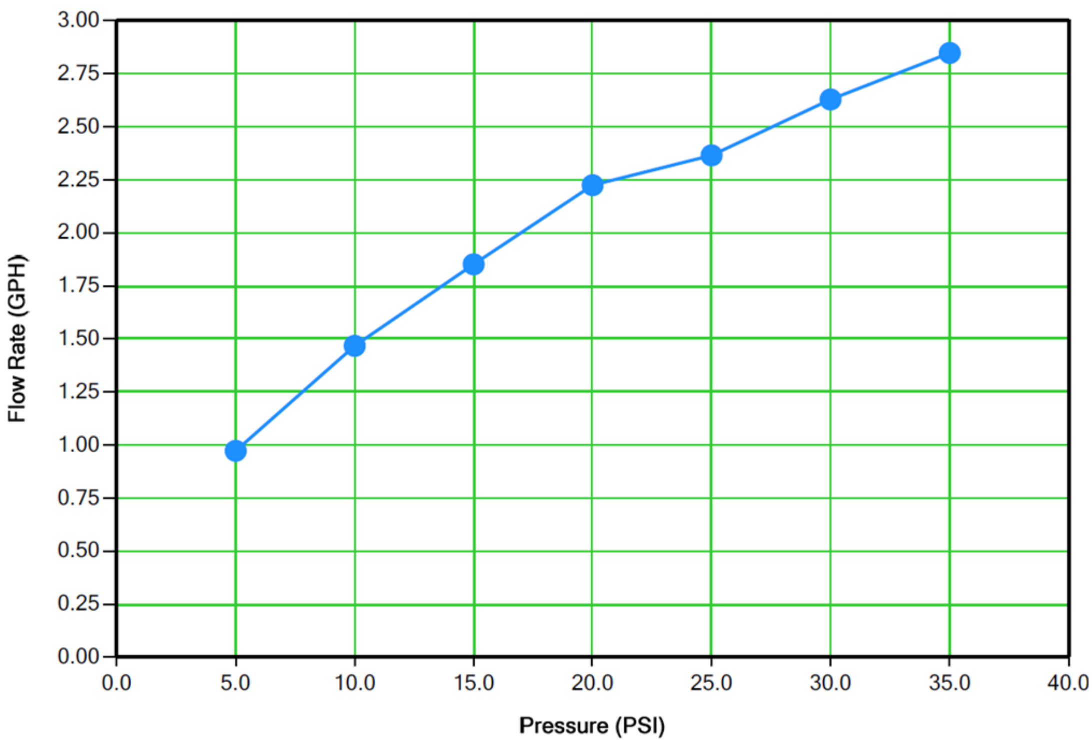
FRESNO STATE
Center for Irrigation Technology

5370 N Chestnut Ave M/S OF18
Fresno, CA 93740-8021
559.278.2066 FAX 559.278.6033
www.californiawater.org()

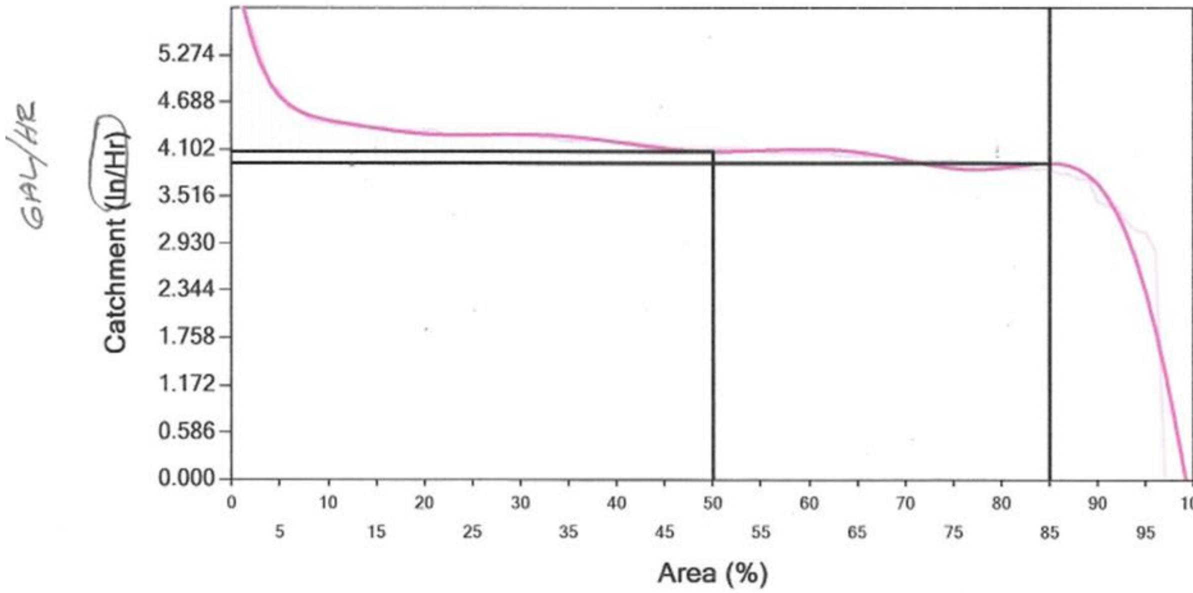
FRESNO STATE
International Center
for Water Technology

Emitter Description	: DRI_2gph
Manufacturer	: DRI
Supplier	: DRI
Test Date	: 04/25/16
Number Tested	: 25

Pressure (PSI)	Temp (°F)	Mean Flow (GPH)	Std. Dev. (GPH)	Mfg's Cv	EU (%)	CU (%)	Emitter Constant	Emitter Exponent
5.0	74.5	0.973	0.09	0.090	89	93		
10.0	75.6	1.468	0.14	0.093	88	93	0.380	0.587
15.0	76.3	1.852	0.16	0.088	88	93	0.367	0.598
20.0	75.2	2.225	0.18	0.080	90	94	0.518	0.487
25.0	64.6	2.365	0.20	0.086	89	93	0.637	0.407
30.0	65.1	2.630	0.24	0.090	89	93	0.400	0.554
35.0	66.4	2.849	0.24	0.085	89	93		



The flow rate of the drip emitters and DRI units attached with them in the field was tested next by collecting field data and the results are represented below.



Pressure (psi):	0.0
Flow Rate (gpm):	0.00
Spacing (ft):	20.0 x 20.0
Area: 6/H	Square
Avg Application Rate (In/Hr):	4.074
Effective Application Rate (In/Hr):	3.932 (85.0 %)
Overspray: G/H	0.0 %
Pattern Loss:	6.8 %
Application Efficiency:	93.2 %
Distribution Uniformity:	77.1 %
Notes:	Deep Root Irrigation Project Almond trees with DRI units attached. Project No. 1488(DRI-15)

Figure 45: Irrigation water distribution uniformity test result

This uniformity study on the DRI almond block was conducted by the Center for Irrigation Technology's senior Agricultural Engineer with the assistance of student researchers. Field data was collected and analyzed. The analysis result showed a pattern loss of 6.8% and an application efficiency of 93.2%.

Appendix E: Applied Water from Flow Meter

Table 20: Applied water from flow meter from April 2017 to September 2018

Date	Avg Flowrate (GPH)	Total HRs Irrigated/week	Flow(Acreft/hr)	Flow(Acreft/Week)
4/2/2017	1353.81	5	0.00	
4/4/2017	1314.12	4	0.00	
4/1/17 to 4/7/17				0.04
4/13/2017	1255.04	6	0.00	
4/8/17 to 4/14/17				0.02
4/15/2017	1271.68	6	0.00	
4/18/2017	750.15	3	0.03	
4/20/2017	1279.29	4	0.00	
4/15/17 to 4/21/2017				0.13
4/25/2017	1280.24	4	0.00	
4/27/2017	1214.24	6	0.00	
4/22/17 to 4/28/18				0.04
4/29/2017	1247.84	6	0.00	
4/29/17 to 4/30/2017				0.03
5/2/2017	1405.84	6	0.00	
5/4/2017	1369.44	6	0.00	
5/6/2017	1340.96	6	0.00	
5/1/17 to 5/7/17				0.08
5/9/2017	1057.92	6	0.00	
5/11/2017	1572.96	6	0.00	
5/13/2017	2361.36	6	0.01	
5/8/17 to 5/14/17				0.09
5/16/2017	1449.13	5.5	0.00	
5/18/2017	1119.76	4	0.00	
5/20/2017	988.47	4	0.00	
5/15/17 to 5/21/17				0.05
5/25/2017	986.94	4	0.00	
5/27/2017	1163.29	4	0.00	
5/22/17 to 5/28/17				0.03
5/30/2017	1032.59	4	0.00	
5/29/17 to 5/31/17				0.01
6/1/2017	1033.57	12.25	0.00	
6/2/2017	1000.08	6	0.00	
6/3/2017	1047.24	12	0.00	

Date	Avg Flowrate (GPH)	Total HRs Irrigated/week	Flow(Acreft/hr)	Flow(Acreft/Week)
6/5/2017	735.20	6	0.00	
6/6/2017	1124.96	12	0.00	
6/7/2017	1100.24	6	0.00	
6/1/17 to 6/7/17		54.25		0.17
6/8/2017	1041.36	12	0.00	
6/9/2017	873.68	6	0.00	
6/10/2017	1114.80	12	0.00	
6/12/2017	855.53	4	0.00	
6/13/2017	1127.12	6	0.00	
6/8/17 to 6/14/17				0.12
6/15/2017	1081.84	6	0.00	
6/16/2017	881.04	5.25	0.00	
6/17/2017	865.78	11	0.00	
6/18/2017	811.62	14	0.00	
6/19/2017	984.54	9.75	0.00	
6/20/2017	1140.31	4	0.00	
6/21/2017	905.82	8	0.00	
6/15/17 to 6/21/17				0.17
6/22/2017	887.16	9	0.00	
6/23/2017	805.09	8	0.00	
6/24/2017	904.79	8	0.00	
6/25/2017	875.00	5.25	0.00	
6/26/2017	841.30	5	0.00	
6/27/2017	972.20	14	0.00	
6/28/2017	912.36	8.25	0.00	
6/22/17 to 6/28/17				0.16
6/29/2017	1003.56	7.75	0.00	
6/29/17 to 6/30/17				0.02
7/1/2017	912.85	8	0.00	
7/2/2017	844.00	1	0.00	
7/3/2017	813.70	8	0.00	
7/4/2017	1027.73	14	0.00	
7/5/2017	1041.76	8	0.00	
7/6/2017	1055.19	6.25	0.00	
7/1/17 to 7/7/17				0.13
7/8/2017	922.42	8	0.00	
7/10/2017	836.31	6.75	0.00	
7/11/2017	960.69	14.25	0.00	

Date	Avg Flowrate (GPH)	Total HRs Irrigated/week	Flow(Acreft/hr)	Flow(Acreft/Week)
7/12/2017	815.59	8	0.00	
7/13/2017	810.23	14.75	0.00	
7/14/2017	840.82	9.25	0.00	
7/8/17 to 7/14/17		61		0.16
7/15/2017	983.90	14.75	0.00	
7/16/2017	882.67	1.25	0.00	
7/18/2017	2384.15	9.25	0.01	
7/19/2017	1834.33	2.5	0.01	
7/21/2017	2466.13	7.75	0.01	
7/15/17 to 7/21/17		35.5		0.19
7/22/2017	2430.73	14.5	0.01	
7/23/2017	1603.33	1.75	0.00	
7/24/2017	2343.15	8	0.01	
7/25/2017	2245.33	8	0.01	
7/27/2017	2197.21	8	0.01	
7/22/17 to 7/28/17		40.25		0.27
7/29/2017	2200.61	8	0.01	
7/29/2017 to 7/31/17				0.05
8/1/2017	2230.06	8	0.01	
8/1/17 to 8/7/17				0.05
8/14/2017	2210.83	7	0.01	
8/8/17 to 8/14/17				0.05
8/15/2017	2269.94	8	0.01	
8/15/17 to 8/21/17				0.06
8/25/2017	2015.42	6.25	0.01	
8/26/2017	2002.79	8	0.01	
8/28/2017	1917.41	7.5	0.01	
8/22/17 to 8/28/17		21.75		0.13
8/29/2017	1934.06	8	0.01	
8/30/2017	1781.64	6.75	0.01	
8/31/2017	1923.31	8.5	0.01	
8/29/17 to 8/31/17		23.25		0.13
9/2/2017	2090.36	8	0.01	
9/5/2017	2045.39	8	0.01	
9/7/2017	2138.42	8	0.01	
9/1/17 to 9/7/17		24		0.15
9/9/2017	2071.63	12	0.01	

Date	Avg Flowrate (GPH)	Total HRs Irrigated/week	Flow(Acreft/hr)	Flow(Acreft/Week)
9/11/2017	1916.61	8	0.01	
9/8/17 to 9/14/17		20		0.12
9/16/2017	1478.29	1.5	0.00	
9/19/2017	1837.60	5.75	0.01	
9/20/2017	1847.20	7	0.01	
9/21/2017	1840.32	6	0.01	
9/15/17 to 9/21/17		20.25		0.11
9/22/2017	1572.67	5.75	0.00	
9/23/2017	1827.06	8.5	0.01	
9/24/2017	1728.00	7	0.01	
9/25/2017	1670.91	5	0.01	
9/28/2017	1976.48	6	0.01	
9/22/17 to 9/28/17		32.25		0.17
9/29/2017	1851.90	9	0.01	
9/30/2017	1964.24	4	0.01	
9/29/17 to 9/30/17				0.08
4/9/2018	1932.67	2	0.01	
4/10/2018	2030.11	4.25	0.01	
4/12/2018	2079.33	3.75	0.01	
4/8/18 to 4/14/18		10		0.07
4/18/2018	2061.18	4	0.01	
4/20/2018	1886.00	3.5	0.01	
4/21/2018	1369.00	0.75	0.00	
4/15/18 to 4/21/18		8.25		0.04
4/25/2018	2061.18	4	0.01	
4/27/2018	1709.53	4	0.01	
4/22/18 to 4/28/18				0.05
4/29/2018	2041.53	4	0.01	
4/29/18 to 4/30/18				0.03
5/1/2018	1998.05	10	0.01	
5/3/2018	2041.41	8.25	0.01	
5/6/2018	2179.21	8	0.01	
5/7/2018	1895.45	8	0.01	
5/1/18 to 5/7/18		34.25		0.21
5/10/2018	2178.55	8	0.01	
5/11/2018	2094.97	8	0.01	
5/12/2018	1685.20	6	0.01	

Date	Avg Flowrate (GPH)	Total HRs Irrigated/week	Flow(Acreft/hr)	Flow(Acreft/Week)
5/13/2018	2117.64	8	0.01	
5/14/2018	1938.85	8	0.01	
5/8/18 to 5/14/18		38		0.23
5/17/2018	2054.12	8	0.01	
5/20/2018	2087.52	8	0.01	
5/21/2018	2021.39	8	0.01	
5/15/18 to 5/21/18		24		0.15
5/23/2018	1973.50	2.75	0.01	
5/24/2018	1903.59	16	0.01	
5/25/2018	2099.64	2.5	0.01	
5/28/2018	1990.42	8	0.01	
5/22/18 to 5/28/18		29.25		0.18
5/29/2018	2062.00	8	0.01	
5/30/2018	1835.50	1.75	0.01	
5/31/2018	1928.89	10.75	0.01	
5/29/18 to 5/31/18		20.5		0.12
6/1/2018	1870.85	6.5	0.01	
6/2/2018	2002.91	8	0.01	
6/4/2018	1843.40	4.75	0.01	
6/5/2018	1888.79	7	0.01	
6/6/2018	2030.81	7.75	0.01	
6/7/2018	1789.68	6	0.01	
6/1/18 to 6/7/18		40		0.23
6/8/2018	1954.50	3.75	0.01	
6/11/2018	2024.97	8	0.01	
6/12/2018	2058.86	15.5	0.01	
6/13/2018	1417.50	1	0.00	
6/8/18 to 6/14/18		28.25		0.16
6/15/2018	2139.84	12.5	0.01	
6/19/2018	2142.06	8	0.01	
6/21/2018	1960.94	7.75	0.01	
6/15/18 to 6/21/18		28.25		0.18
6/23/2018	2128.06	8	0.01	
6/26/2018	2084.73	8	0.01	
6/28/2018	2093.21	8	0.01	
6/22/18 to 6/28/18		24		0.15
7/3/2018	2119.70	8	0.01	

Date	Avg Flowrate (GPH)	Total HRs Irrigated/week	Flow(Acreft/hr)	Flow(Acreft/Week)
7/5/2018	1931.47	4.5	0.01	
7/6/2018	2225.11	6.25	0.01	
7/7/2018	2193.27	8	0.01	
7/1/18 to 7/7/18		26.75		0.17
7/8/2018	2126.06	8	0.01	
7/9/2018	2110.49	16	0.01	
7/10/2018	1983.27	2.5	0.01	
7/12/2018	2092.85	8	0.01	
7/14/2018	2100.55	8	0.01	
7/8/18 to 7/14/18		42.5		0.27
7/16/2018	2017.79	6.75	0.01	
7/17/2018	2180.81	6.5	0.01	
7/18/2018	1680.00	0.75	0.01	
7/19/2018	1762.00	0.75	0.01	
7/21/2018	1794.80	1	0.01	
7/15/18 to 7/21/18		15.75		0.09
7/24/2018	2009.82	8	0.01	
7/26/2018	2052.48	8	0.01	
7/28/2018	2061.21	8	0.01	
7/22/18 to 7/28/18		24		0.15
7/31/2018	1994.55	8	0.01	
7/29/18 to 7/31/18				0.05
8/2/2018	1783.33	1.25	0.01	
8/1/18 to 8/7/18				0.01
8/9/2018	2155.53	12.25	0.01	
8/10/2018	1989.82	8	0.01	
8/11/2018	2110.91	8	0.01	
8/12/2018	2065.82	8	0.01	
8/13/2018	1964.11	8.25	0.01	
8/14/2018	2097.70	8	0.01	
8/8/18 to 8/14/18		52.5		0.33
8/16/2018	1987.03	8	0.01	
8/18/2018	2008.73	2.25	0.01	
8/15/18 to 8/21/18		10.25		0.06
9/3/2018	2477.00	2.75	0.01	
9/4/2018	2114.91	8	0.01	
9/5/2018	2016.85	8	0.01	
9/6/2018	2006.91	8	0.01	

Date	Avg Flowrate (GPH)	Total HRs Irrigated/week	Flow(Acreft/hr)	Flow(Acreft/Week)
9/7/2018	1914.61	5.5	0.01	
9/1/18 to 9/7/18		32.25		0.21
9/8/2018	818.15	6.25	0.00	
9/11/2018	1736.72	12.5	0.01	
9/13/2018	2043.04	6	0.01	
9/8/18 to 9/14/18		24.75		0.12
9/15/2018	2022.72	6	0.01	
9/18/2018	1982.88	12	0.01	
9/20/2018	2201.60	6	0.01	
9/15/18 to 9/21/18		24		0.15
9/22/2018	1891.20	6	0.01	
9/25/2018	2016.64	6	0.01	
9/27/2018	1892.40	4.75	0.01	
9/22/18 to 9/28/18		16.75		0.10
9/29/2018	2018.40	6	0.01	
9/29/18 to 9/30/18				0.04