Final report

A. Project Information:

Project Title: Improving nitrate and salinity management strategies for almond grown under micro-irrigation

Grant Number: 15-0523-SA

Project Leader:

- ***Patrick Brown***, Professor, Dept. Plant Science, University of California, Davis, CA 95616, phbrown@ucdavis.edu

B. Objectives:

The objective of this project is to evaluate the effect of irrigation management (high vs. low frequency) and soil type (course vs. fine texture) on concentration and patterns of deposition of salt within the root zone, root growth and the effect on N uptake by different rootstocks (salt-tolerant vs. salt-sensitive) of almond. The research is being conducted in large lysimeters and in commercial orchards. The large lysimeters (8 x 28 x 5 ft) are used to provide a semi-field scale controlled experiment and will allow growth of trees to full commercial size. Data from different treatments has been used to evaluate a variety of soil/plant factors and derive parameters. Specifically, we are quantifying leaching of nitrate and water movement in, and below the root zone of almond trees, the patterns of accumulation of salts in the soil, plant and soil water relationships and crop response in terms of growth and tree nitrogen status.

The collected data will be used to validate and if necessary calibrate an existing modeling platform, HYDRUS 2D. This model will then be used as an integrated water and nitrate management tool to develop alternative irrigation/fertigation methods for different almond cultivars, soil types, and salinity. The ultimate goal of this project is to provide grower guidelines for irrigation and fertigation strategies to minimize leaching of nitrate below the root zone while maintaining the growth and yield at optimum level and maintaining a balanced salt concentration in the root zone of the trees.

This project will be coordinated with Almond Board (ABC) funded studies of the physiology of almond rootstock response to salinity that is being conducted in pot and solution culture experiments. The two activities are highly complimentary. Together, this research program, will characterize the salinity and ion tolerance of modern almond rootstocks and cultivars, develop guidelines for coincident salinity and nitrate management under MI, and develop and present a series of on-line, print and model driven extension materials to ensure effective outreach and implementation of findings. The ABC in collaboration with SureHarvest have a developed a web portal available free of charge to all almond growers and maintained with ABC funds (http://www.almonds.com/growers/sustainability), this portal and the UC maintained Fruit and Nut Center Web Portal (http://fruitsandnuts.ucdavis.edu) will ensure that information and advances made in

this project are permanently available, updated and maintained.
This project has recently received a funding extension to allow trees to reach 7 years of age (approaching full maturity) so that a full 4 years of data can be accumulated, many of the following objectives and outcomes are therefore ongoing.

1. To characterize the patterns of root nitrate uptake and plant response when plants are grown with roots in soils of different salinity status (as typically occurs under micro-irrigation).
2. To use HYDRUS to model solute transport, plant response (water and nitrate uptake) to salinity, and specific ions (Cl, Na, B) under a variety of irrigation scenarios and different conditions such as soil type, environment, timing, distribution, irrigation system, and water quality.
3. To use the information in objectives 1 and 2 to develop site and cultivar specific models and guidelines for nitrate sensitive salinity management and to produce a series of written and online grower guidelines and tools for irrigation design and scheduling.
4. To produce a robust modeling platform for the advanced grower, consultant, advisor, irrigation industry representative and researcher to develop novel and site specific irrigation design and scheduling practices for nitrate sensitive salinity management.

C. Abstract:

We have commenced the evaluation of the effect of irrigation management and soil type on the deposition pattern of salt within the root zone, and the consequent effect on N uptake by different rootstocks (salt-tolerant vs. salt-sensitive) of almond. Trees were planted in 2015 in 24 large lysimeter and the root zone has been instrumented to collect the data on water, salts, nitrate, and root growth. The collected data has been used to validate and calibrate an existing modeling platform, HYDRUS and develop a modeling platform that will be linked to an inverse modeling framework for estimation of physical and biological parameters that determine nitrate, salinity and water fluxes. Once the required parameters are obtained, this model will be used as an integrated water and nitrate management tool to develop alternative irrigation/fertigation methods to optimize nitrate uptake and minimize salinity effects for different varieties of almond cultivar, soil types, and level of salinity. The ultimate goal of this project is to provide grower guidelines to minimize leaching of nitrate below the root zone while maintaining the growth and yield at optimum level and a balanced salt concentration in the root zone of the trees.

D. Introduction

The majority of almond growers currently provide N fertilization in liquid form through micro-irrigation systems (drip and micro-spray) and increasingly growers are utilizing ground water that is saline. Irrigation strategies, fertigation management, nitrate leaching and salinity management are therefore linked and strategies must be developed that optimize productivity while minimizing nitrate leaching and avoiding salt-induced stress to almond trees. There has been very little research to explicitly co-optimize nutrient and water use efficiency and no research that we are aware of to guide irrigation strategies for the dual goal of managing both nitrate and salinity in almond trees. Perennial species and micro-irrigation impose unique challenges for salinity management and strategies developed for annual crops are not optimized for tree crops. Specifically 1) almond is highly salt sensitive and as water quality diminishes greater leaching volumes will be required, 2) micro-irrigation results in local salt deposition at the lateral and vertical margin of the wetting pattern, water and nitrate within this high salt margin will not be available for uptake, 3) if not conducted properly, strategies that optimize salt leaching to the periphery of the rooted zone will simultaneously leach nitrate.

While micro-irrigation (MI) methods are effective in boosting productivity and improving water/nutrient use efficiency, MI does result in a smaller rooting zone and in a highly non-uniform salt deposition (toward the edge of wetting pattern) in the active rooting zone. This has negative consequences for nitrate management since nitrate that is pushed into the high salt regions at the periphery of the wetted zone will not be available to plant roots and hence is vulnerable to leaching. Salinization of the margins of wetting pattern decreases the volume of soil in which roots can optimally function hence plant response to salinity will be determined not by bulk soil salinity but by the salinity within the active root zone and by the proportional distribution and activity/tolerance of roots in the saline (close to the edges of wetting zone) and non-saline (near the center of wetting zone) zones within the rooted profile. The challenge of developing meaningful salinity management strategies under MI is further complicated by our relative lack of knowledge of the responses of almond to salinity. Almond is considered a salt-sensitive crop with a threshold EC of 1.5 dS/m, these values, however, was derived for Lovell rootstock under flood irrigation and are no longer relevant to modern almond systems. Rootstocks and cultivars of almond are known to vary dramatically in their sensitivity to salt induced water stress and vary in their susceptibility to the effects of toxic ions, Na and Cl.
Given the complexity of solute management under MI and the lack of information on almond rootstock response to salinity and the lack of information on the effects of salinity on root distribution and nitrate uptake it is virtually impossible for growers to make informed irrigation management decisions that satisfy the dual goal of minimizing root zone salinity while simultaneously minimizing nitrate leaching. Developing this understanding is the primary goal of this research proposal.

For diverse reasons the most prevalent micro irrigation schedule in California is for growers to use long irrigation durations (commonly 24 hrs with occasional 48 hrs) and to apply nitrogen in 4 or fewer injected fertilizer applications during the year. This approach is in stark contrast to practices in Australia, Spain and Israel where microirrigation and fertigation schedules are more commonly daily or even hourly. Spoon-feeding in this way has the potential to improve irrigation and consequently fertilizer management. While recent FREP funded research has provided clear biological rationale for the adoption of frequent spoon-feeding of nitrogen, this has not yet been widely adopted, possibly because of the added infrastructure and personnel costs that spoon-feeding may incur. The threat of salinity and the development of irrigation strategies to achieve the goal of minimal salinity and minimal leaching will serve as an additional impetus for the adoption of spoon-feeding approaches to irrigation and fertilization.

E. Work description:

Task 1. Experimental design and instrumentation:

a) Experimental design

Almond trees were established in 2015 at the UCD Plant Sciences field research facility in large tomato truck bins measuring 28 × 8 × 4 ft (L×W×D). Field ground was leveled with a slight slope allowing for movement of water toward the outlets of bins. Drainage pipe was installed at the bottom of each bins (Fig. 1A) to facilitate the collection of leachate and was covered by coarse sand and then filled with loamy sand soil (Fig. 1B). Drip irrigation and fertilizer injection systems were installed and are operational. Fertilizer is injected into the irrigation water at a constant ratio using water-driven injection pumps. The trees are irrigated using two parallel driplines on each tub. There are eight emitters for each tree and each emitter emits water at a rate of 0.5 gallons per hour. The experiment was designed for six treatments and four replicates for a total of 48 almond trees (24 Nonpareil grafted on Nemaguard rootstock and 24 Nonpareil grafted on a Viking rootstock). Each tub contains one tree with a Nemaguard rootstock and one tree with a Viking root stock (Fig. 1C,D,E). Rain-out shelters were built for the tubs to prevent patterns of salt accumulation in the soil from being leached out during the rainy winter season (Fig. 1F).

Fig. 1: Construction of the 24 drainage lysimeters. A- Drainage pipe covered with a screen and connected to an outlet in the wall of the tomato truck bin. B- Bin being filled with a layer of coarse sand at the bottom and loamy soil above. C- Young almond trees after transplanting into the bins. D- Trees after having grown in the bins for one year. E-

Trees during summer 2018. F- Rain-out shelters that will cover the tubs during most of the rainy winter season to prevent excessive leaching.

Six additional bins were installed and are used as weighing lysimeters (Fig. 2A). Each bin rests on four load cells that measure the mass of the lysimeter (Fig. 2B). A drainage pipe consisting of PVC pipe with slots covered with a screen was installed in each lysimeter with an outlet at the bottom of the lysimeter (Fig. 2C). The drainage pipe was covered with an approximately 20 cm thick layer of coarse sand and the remaining depth of the lysimeter was then filled with a loamy soil (Fig. 2D,E). A drip irrigation system was installed that allows for three irrigation treatments and two replicates per treatment.

Fig. 2: Setup of the weighing lysimeters. A- Fiberglass bins with railings for safety installed at the experimental site. B- Load cell. C- Drainage system consisting of perforated PVC pipe covered with a screen. D- Bin after adding the first layer of soil. E- Bins after filling with soil and before levelling the soil.

b) Instrumentation plan and data collection methods

Neutron probe access tubes were installed in the tomato truck tubs by augering holes into the soil and installing PVC tubes with a plug at the lower end. There are three access tubes per tree in three of the four replicates at different distances from the tree and from the driplines (Fig. 3A). Soil samples of a known volume were taken from some of the holes while augering them in order to measure the actual volumetric water content and compare it to the readings of the neutron probe that were taken a short time after augering the hole and installing the access tube (Fig. 3B).

Mini-rhizotron access tubes were installed in six of the tubs (two different treatments in the finer textured soil) in the root zone of the Nemaguard trees. The acrylic tubes were installed horizontally through the wall of the bin at 30 and 70 cm depth. Pictures of the roots will be taken regularly and will be used to quantify root distribution over time.

Thermocouples were built from type T thermocouple wire (Omega Engineering, Inc.), tested for variability between sensors in a water bath and installed in the weighing lysimeter bins at 20 cm, 80 cm, and 175 cm depths at each wall of each lysimeter (Fig. 3D,E,F). The load cells for measuring lysimeter mass were calibrated by placing objects with known weight on top of the lysimeter while recording the readings of the load cells. Metal pipes and sand-filled buckets were used as weights and loaded onto the lysimeter in five large increments of about 100 kg and three smaller increments (Fig. 3C). During the process, the lysimeters were covered with tarp to prevent evaporation from the soil surface.

A system for measuring and recording the sensor output was setup that consists of one central datalogger (Fig. 3H) and six analog input modules (Campbell Scientific, Inc.) that are connected to the central datalogger by wires which were run through flexible conduit (Fig. 3G). The conduit was then buried in the soil.

Fig. 3: Instrumentation of the 24 drainage lysimeters and the six weighing lysimeters. A- Neutron probe access tubes installed in the soil. B- Taking soil moisture samples at various soil depth for neutron probe calibration. A level was used as a height reference to ensure that depth measurements are consistent between the access tubes at one tree. C- Calibration of the load cells by adding known weights to the surface of the lysimeter after covering the surface with tarp to reduce evaporation from the soil. D- Thermocouples made from type T thermocouple wire. E- Testing the variation between thermocouples by placing them in a water bath inside of a cooler. F- Installation of a thermocouple at 80 cm depth by digging a hole from the top. G- Logger boxes mounted on t-posts in front of each lysimeter. The flexible conduit that the cables were run

through to connect each box to the central data logger was later buried in the soil. H- Main data logger, analogue input module for measuring load cells and thermocouple outputs, battery and charge controller.

c) Soil hydraulic properties

Soil hydraulic properties were determined using three different methods with the objective to use this information in simulation models. In-situ near saturated hydraulic conductivity was measured using a tension disk infiltrometer (Decagon Devices, Inc., Fig. 4A). Using the device, water was infiltrated into the soil while maintaining a soil water tension of 1 cm at the soil surface. The saturated conductivity was then calculated from the observed volume of infiltrated water at different times for each measurement. Measurements were taken for several randomly selected tubs at several locations within the tub.

Water retention curves and unsaturated hydraulic conductivity of undisturbed soil cores were measured using the HYPROP device (METER, Inc., Fig. 4B). The device continuously measures the tension of the soil water using tensiometers and volumetric water content by weighing the sample while the sample dries from close to full saturation to the measurement limit of the tensiometers.

Soil texture was analyzed by taking samples from various soil depths at various locations and analyzing for particle size distribution using the hydrometer method. In addition, the sand fraction was separated from the suspension used for the hydrometer method and quantified by passing the suspension through a sieve and drying and weighing the sand. The texture data will be used to predict soil hydraulic properties using empirical models (e.g. ROSETTA or Neuro Multistep).

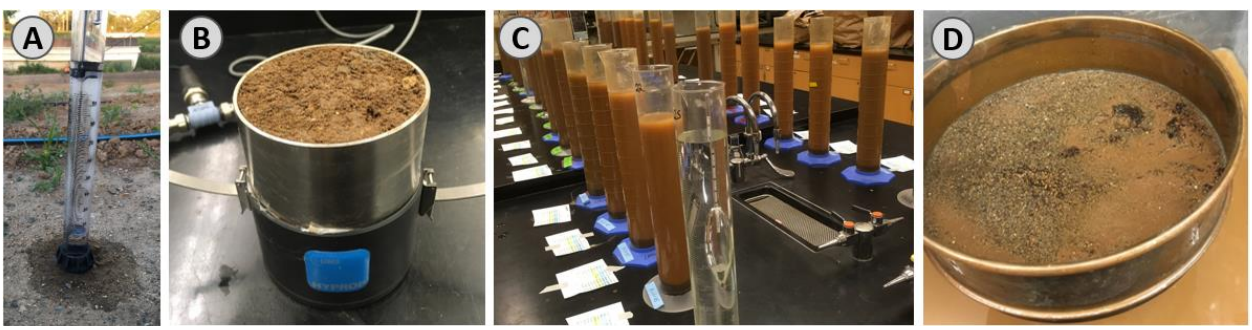

Fig. 4: Measurement of soil properties. A- Measuring near saturated hydraulic conductivity in the field using a tension disk infiltrometer. B- Measuring retention curve and unsaturated hydraulic conductivity curve of undisturbed soil samples using the HYPROP device. C- Texture analysis using the hydrometer method. D- Determining the mass of the sand fraction by wet sieving.

Task 2:

a) Tree Growth and Development and Nutrient Analysis

Tree growth was quantified by measuring stem diameter at different points in time. Nutrient status of the trees were determined by analyzing leaf samples for nutrient concentrations in 2016 and 2017.

b) *Quantifying leaching and N use efficiency*

Leaching will be quantified by measuring amount and concentrations of salt (EC) and nutrients of the water that reaches the drainage tubes at the bottom. The water is collected using buckets that are connected to the end of the drainage tubes at the bottom of each tub.

Task 3. Modeling Scenario analysis:

a) *HYDRUS calibration*

A split root methodology in which roots of a single plant were divided in two equal halves and different saline treatments were applied to different areas of the root system was performed. Split roots experiment using: Nemaguard seedlings (for solution culture) and Nonpareil trees grafted on three different rootstocks were used to measure root response under heterogeneous saline condition and its effect in the short term (28 days/hydroponics) and long term (2 growing seasons/substrate). Plant growth and root activity (uptake of water, salt ions and mineral nutrients) were measured to understand plant-soil dynamics. This set of experiments was used to identify the parameters required for model development.

b) *HYDRUS validation*

The model will be validated using measured data from the lysimeter experiment.

c) *Guideline development*

Guidelines will be developed based on model simulations for various soil types and climatic conditions.

Task 4. Outreach program:

Table 1 lists outreach events where results of the project were presented.

Tab. 1: List of outreach events.

Date	Event	Title
Nov. 2017	**FREP/WPHA conference**, Modesto, CA	**Presentation**: Improving nitrate and salinity management strategies for almond grown under micro-irrigation (Dr. Patrick Brown)
Dec. 2017	**Almond conference**, Sacramento, CA	**Poster**: Salinity Stress in Almond, Rootstock Screening and Tree Response to Non-Uniform Salinity (Dr. Francisco Valenzuela-Acevedo) **Presentation**: Managing salinity in almond (Dr. Francisco Valenzuela-Acevedo)

Feb March 2018	4 Field days (Yolo, Modesto, Fresno, Bakersfield) 300 attendees	Grower Field day on Nitrogen and salinity management (Integrated with CDFA – Demonstration Project)
Nov. 2018	**WHPHA Nutrient Conference**, Modesto, 150 attendees	**Presentation**: Salinity and tree crops (Dr. Patrick Brown)
Dec. 2018	**Almond conference**, Sacramento, CA (2,300 attendees)	**Presentation**: Managing Nutrients and Salt under current Water Quality Regulations (Dr. Patrick Brown) Poster: Salinity Screening for Almond and Tree Response to Non-Uniform Salinity (Dr. Francisco Valenzuela-Acevedo)

F. Data/Results

1. Soil hydraulic properties

Fig. 5 shows the results of the measurements of saturated hydraulic conductivity as well as retention curve and unsaturated hydraulic conductivity curve. The median of the saturated hydraulic conductivity measurements is higher in the loamy sand than in the sandy loam. In addition, the loamy sand shows a larger variation in saturated hydraulic conductivity.

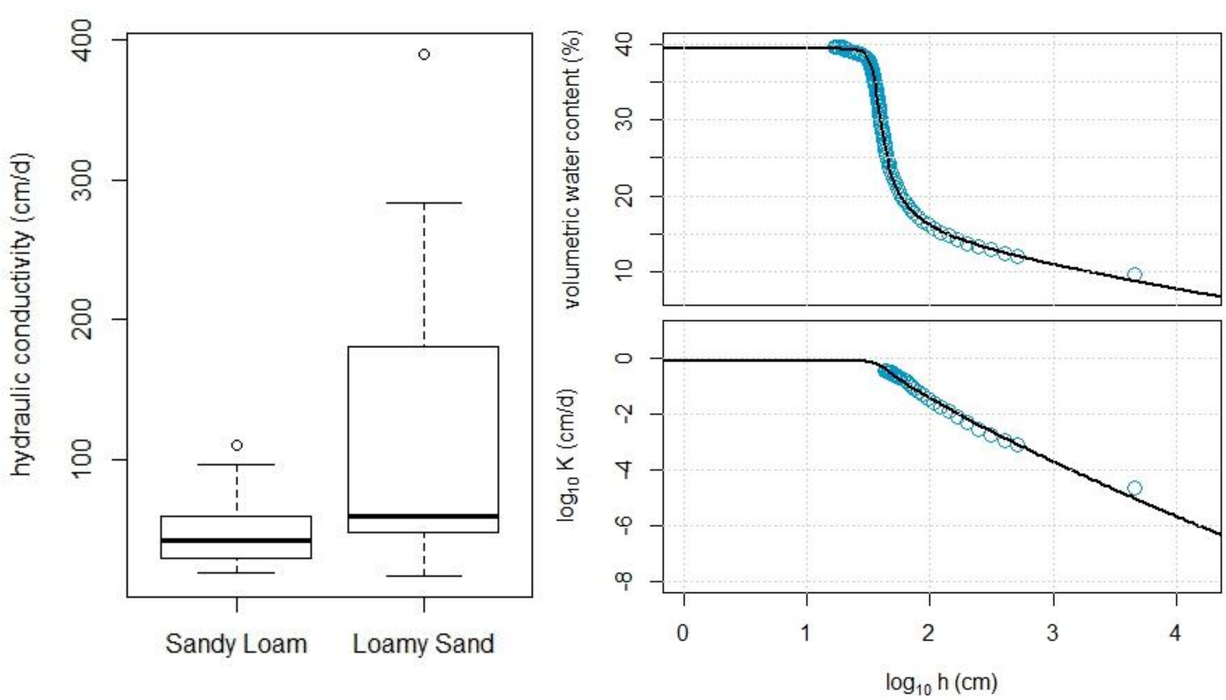

Fig. 5: Results of measurements of soil hydraulic properties. (a) Near saturated hydraulic conductivity for the sandy loam and the loamy sand obtained from tension disk

infiltrometer measurements, (b) point measurements (blue circles) and fitted model (black line) of the retention curve of the loamy sand obtained from the evaporation method and (c) hydraulic conductivity of the loamy sand as a function of pressure head (h) measured using the evaporation method.

2. Split-root experiments

A hydroponic experiment was used to check the effect of salinity in different areas of the root zone on water and nitrate uptake. 45 seedlings of Nemaguard (rootstock commonly used in commercial orchards across California) were used in each experiment. Highly plastic root responses were observed when salinity was applied. Under conditions where nutrients were available in both root-zones, water and ion uptake rapidly allocates to root sub-zones in the non-saline environment (Fig. 6). The uptake of water and saline ions was greatly enhanced in areas of low salinity and diminished in saline root sub-zones; however when nutrients were provided to both root sides, a marked increment in water and salt uptake from the saline root-zone occurs (Table 1).

Results demonstrate that almond root rapidly responds to the local root environment with water uptake greatly diminished in saline root zones if there is availability of non-saline water in other root zones. The availability of nutrients appears to be critical to this response thus suggesting that strategies to leach salts from root zones will only be successful if there are adequate nutrient reserves in the non-salinized portion of the root volume.

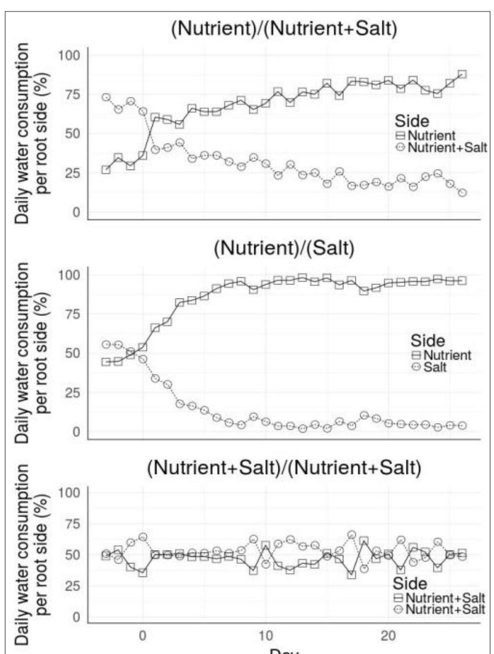

Fig. 6: Daily percent of water consumption from roots in a split root system under hydroponics with Nemaguard seedlings. [Nutrient] (0 mM NaCl; EC = ~0.6 dS/m), [Nutrient+Salt] (60 mM NaCl; EC = ~6.6 dS/m) and [Salt] (66 mM NaCl; EC = ~6.6 dS/m).

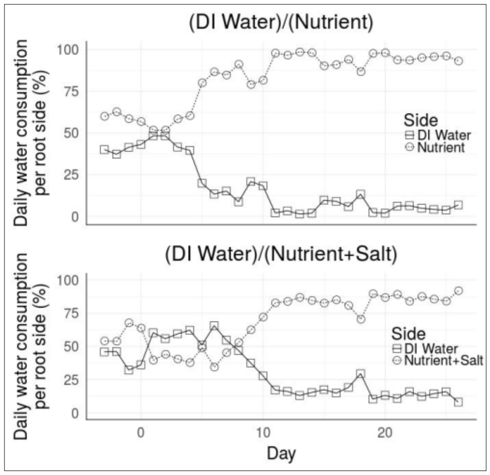

Fig. 7: Daily percent of water consumption from different treated root in a split root system under hydroponics of Nemaguard seedlings. [Nutrient] (0 mM NaCl; EC = ~0.6 dS/m), [DI Water] (0 mM NaCl; EC = 0 dS/m) and [Nutrient+Salt] (60 mM NaCl; EC = ~6.6 dS/m).

Tab. 1: Total nitrate uptake of roots under non-uniform salinity conditions. Measurements were taken during the last day of the experiment (day 28). Means followed by the different letters are significantly different according Tukey test with 95% of confidence.

Treatment	**Root side**	**Total nitrate uptake per plant (µmol per hour)**
Nutrient / Nutrient+Salt	Nutrient	68.3 +/- 6.4b
Nutrient / Nutrient+Salt	Nutrient+Salt	36 +/- 7b
Nutrient / Salt	Nutrient	118.4 +/- 12.3a
Nutrient / Salt	Salt	0 +/- 0d
Nutrient+Salt / Nutrient+Salt	Nutrient+Salt	30.2 +/- 7.1c
Nutrient+Salt / Nutrient+Salt	Nutrient+Salt	27.6 +/- 6.6c

3. Neutron probe calibration

Figure 8 shows the calibration data for the loamy sand. The measurements were taken on different dates to cover a wide span in soil water content.

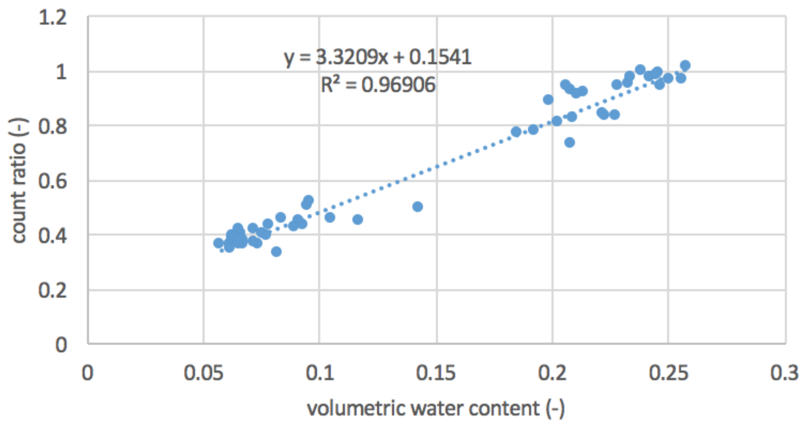

Fig. 8: Neutron probe calibration data for the loamy sand.

4. Load cell calibration

Figure 9 shows the results of the load cell calibration for the weighing lysimeters. The load cell output shows a linear response to the amount of weight added to the lysimeter with an R squared of 0.999.

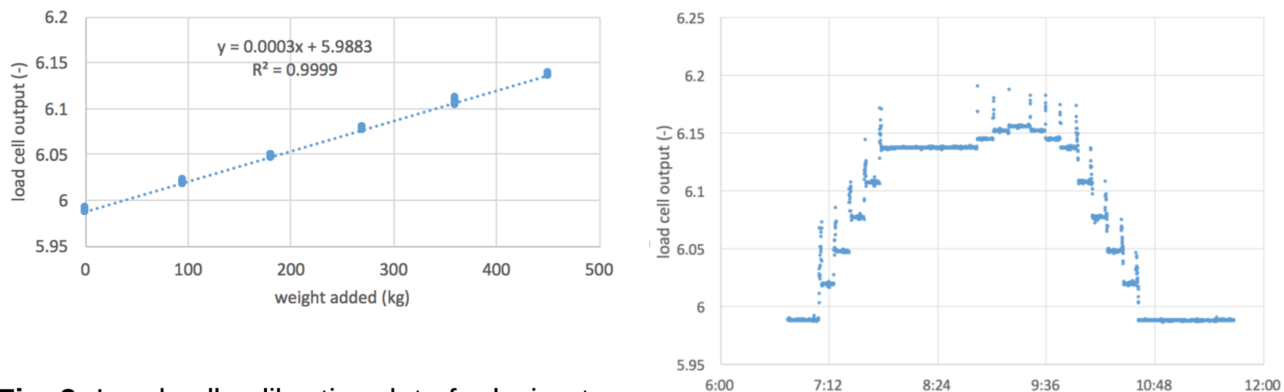

Fig. 9: Load cell calibration data for lysimeter 2: Calibration curve (left) and time series of load cell output during the calibration procedure (right).

5. Temperature

Fig. 10 shows the diurnal variation of temperature measured in the weighing lysimeters in August. For the thermocouples that are located at the lysimeter walls, a high temperature variation can be observed, especially at 20 cm depth. For the thermocouple located in the center at 175 cm depth, the temperature is almost constant during the course of a day.

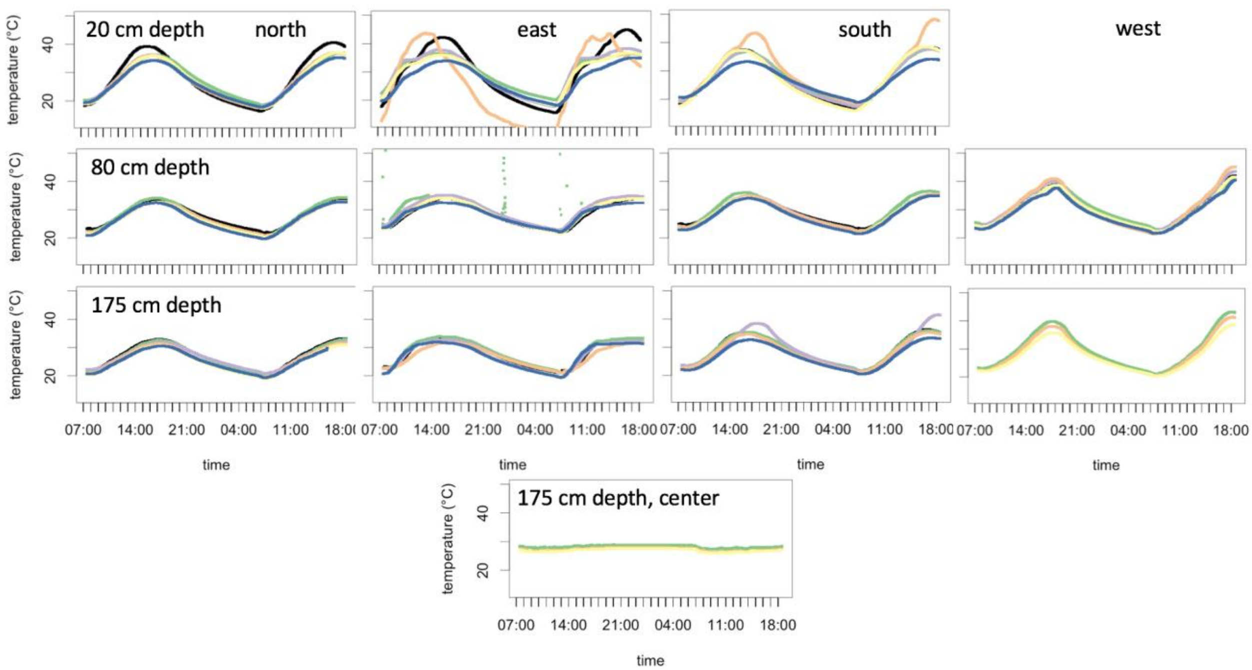

Fig. 10: Diurnal variation of temperature at different positions (north, east, south and west wall at three different depths as well as in the center of the lysimeter at 175 cm depth) in the weighing lysimeters from 08/07/2018 to 08/08/2018. Colors denote different lysimeters. Some data is missing due to technical problems.

G. Discussion and Conclusions

The greenhouse experiments suggest that almond plants are able to control from where water is taken up in response to both salinity and nutrient concentrations, in order to optimize nutrient uptake and limit the amount of toxic ions taken up. This striking effect of nutrients on plant response has tremendous implications for nutrient management in salt affected root zones (Fig. 5). The lack of nutrients in one root zone decreases the water uptake from that zone. If nutrients are limited to the salty root zone then preferential water uptake will occur from the salt side with resultant enhancement of salt uptake. For management, this may mean that it is important to manage irrigation and fertilizer application in a way that the zones where salt accumulates are separated from the zones where nutrient concentrations are highest. How important this is under field conditions and how it can be achieved by irrigation management will be tested using the existing lysimeter experiment.

H. Project Impacts

Results were shared during the almond board of California conference on 2016 and 2017, in the form of poster and oral presentation. Results were also presented at a number of field days and conferences attended by growers, consultants and industry (Table 1). The last ABC conference had 3,900 attendees gathering growers, processors, suppliers, distributors, marketers and researchers from around the globe. Since a large large proportion of the almond production region of California is currently utilizing groundwater and recycled/drainage impacted surface waters containing significant salinity, outputs of this project have a direct impact in the management of those orchards. The research will inform the management of agricultural discharges and will lead to innovation in the irrigation industry and improved policy.

I. Outreach Activities Summary

Due to the very extensive experimental preparations described here and the long time required for tree establishment in the lysimeters the final project outcomes to growers and irrigation professionals (outreach programs) will not be available until the final two years of the grant extension period. We have continued to present a number of outreach events around the general topic of co moanagement of nitrate and salinity and preliminary results have generated considerable interest.

J. Factsheet/Database Template

Project Title: Improving nitrate and salinity management strategies for almond grown under micro-irrigation

Grant Agreement Number: 15-0523-SA

Project Leaders: Patrick Brown, Professor, Dept. Plant Science, University of California, Davis, CA 95616, phbrown@ucdavis.edu

Start Year: 2016; **End Year:** 2018

Location: Davis, CA

County: Yolo County

Highlights

- Experiments were conducted to evaluate the effect of irrigation management and soil type on the deposition pattern of salt within the root zone, and the consequent effect on N uptake by almond trees.
- Experiments in hydroponic systems showed that when different parts of the root system are exposed to different salt/nutrient concentrations, the plants take up water preferentially from where nutrient concentration is high and salt concentration is low.
- The response of root water uptake to changes in salt or nutrient concentrations is fairly quick: After changing the solution, root water uptake adapts within a few days.
- The results suggest that if nutrients are limited to the salty root zone then preferential water uptake will occur from the salt side with resultant enhancement of salt uptake.

Introduction

The majority of almond growers currently provide N fertilization in liquid form through micro-irrigation systems (drip and micro-spray) and increasingly growers are utilizing ground water that is saline. Irrigation strategies, fertigation management, nitrate leaching and salinity management are therefore linked and strategies must be developed that optimize productivity while minimizing nitrate leaching and avoiding salt-induced stress to almond trees. There has been very little research to explicitly co-optimize nutrient and water use efficiency and no research that we are aware of to guide irrigation strategies for the dual goal of managing both nitrate and salinity in almond trees.

Methods/Management

A lysimeter experiment was set up consisting of 24 large lysimeters with 48 almond trees and six weighing lysimeters that will contain six additional trees. The root zone will be instrumented to collect the required data on water, salts, nitrate and root growth to accomplish the objectives of this project. The collected data will also be used to validate and calibrate an existing modeling platform, HYDRUS. Once the required parameters are

obtained, this model will be used as an integrated water and nitrate management tool to develop alternative irrigation/fertigation methods to optimize nitrate uptake and minimize salinity effects for different varieties of almond cultivar, soil types, and level of salinity.
A hydroponic experiment was used to check the effect of salinity in different areas of the root zone on water and nitrate uptake. 45 seedlings of Nemaguard (rootstock commonly used in commercial orchards across California) were used in each experiment. The root system of each plant was split and each half was exposed to different salt/nutrient conditions.

Fig. 1: Construction of the 24 drainage lysimeters. A- Drainage pipe covered with a screen and connected to an outlet in the wall of the tomato truck bin. B- Bin being filled with a layer of coarse sand at the bottom and loamy soil above. C- Young almond trees after transplanting into the bins. D- Trees after having grown in the bins for one year. E- Trees during summer 2018. F- Rain-out shelters that will cover the tubs during most of the rainy winter season to prevent excessive leaching.

Findings

Experiments in hydroponic systems suggest that almond plants are able to control from where water is taken up in response to both salinity and nutrient concentrations, in order to optimize nutrient uptake and limit the amount of toxic ions taken up. This striking effect of nutrients on plant response has tremendous implications for nutrient management in salt affected root zones (Fig. 2). The lack of nutrients in one root zone decreases the water uptake from that zone. If nutrients are limited to the salty root zone then preferential water uptake will occur from the salt side with resultant enhancement of salt uptake. For management, this may mean that it is important to manage irrigation and fertilizer application in a way that the zones where salt accumulates are separated from the zones where nutrient concentrations are highest. How important this is under field conditions and how it can be achieved by irrigation management will be tested using the existing lysimeter experiment.

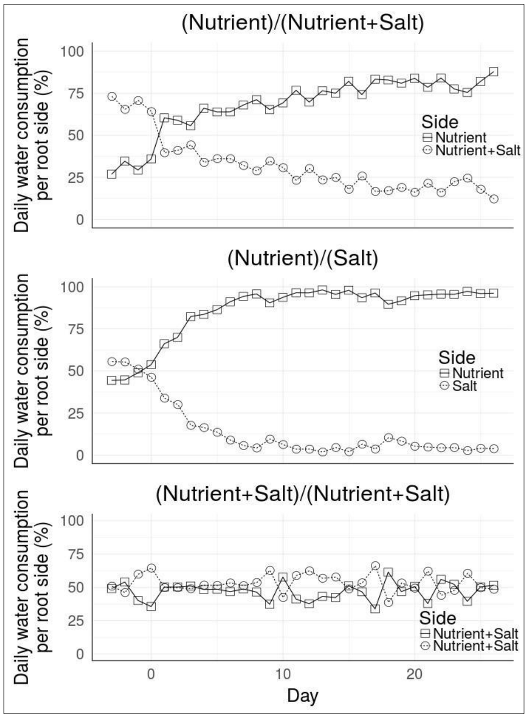

Fig. 2: Daily percent of water consumption from roots in a split root system under hydroponics with Nemaguard seedlings. [Nutrient] (0 mM NaCl; EC = ~0.6 dS/m), [Nutrient+Salt] (60 mM NaCl; EC = ~6.6 dS/m) and [Salt] (66 mM NaCl; EC = ~6.6 dS/m)

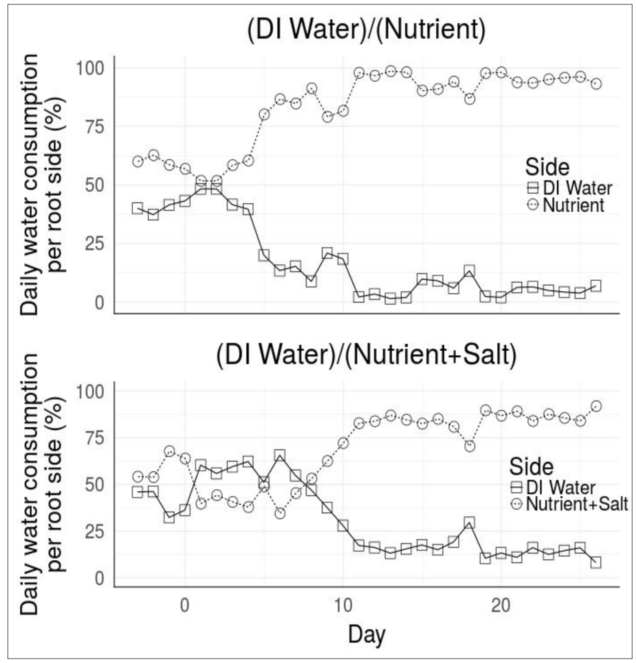

Fig. 3: Daily percent of water consumption from different treated root in a split root system under hydroponics of Nemaguard seedlings. [Nutrient] (0 mM NaCl; EC = ~0.6 dS/m), [DI Water] (0 mM NaCl; EC = 0 dS/m) and [Nutrient+Salt] (60 mM NaCl; EC = ~6.6 dS/m).

Copy of the Product/Results

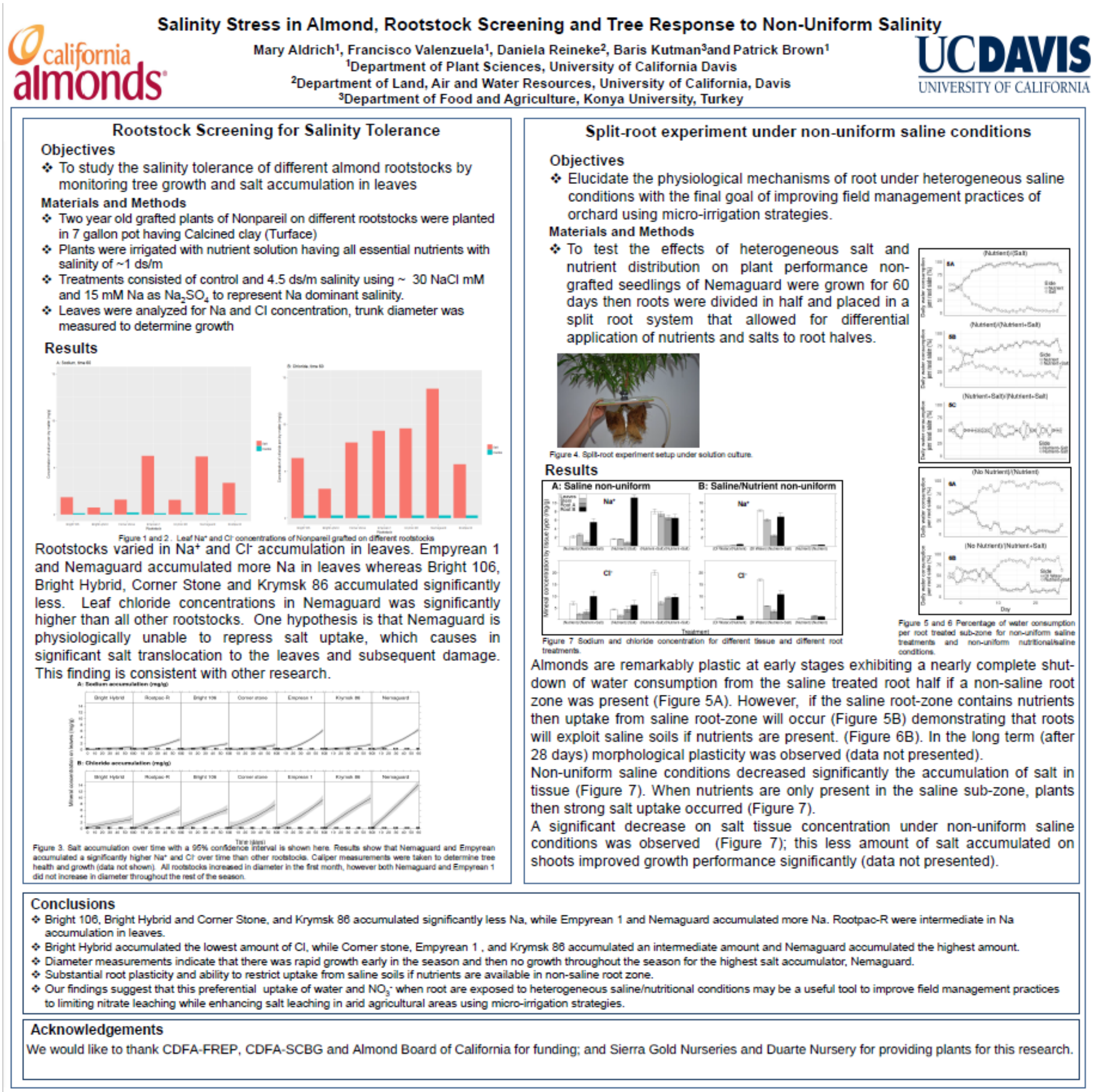

Fig. 11: Poster presented at the Almond Conference in Sacramento in December 2017

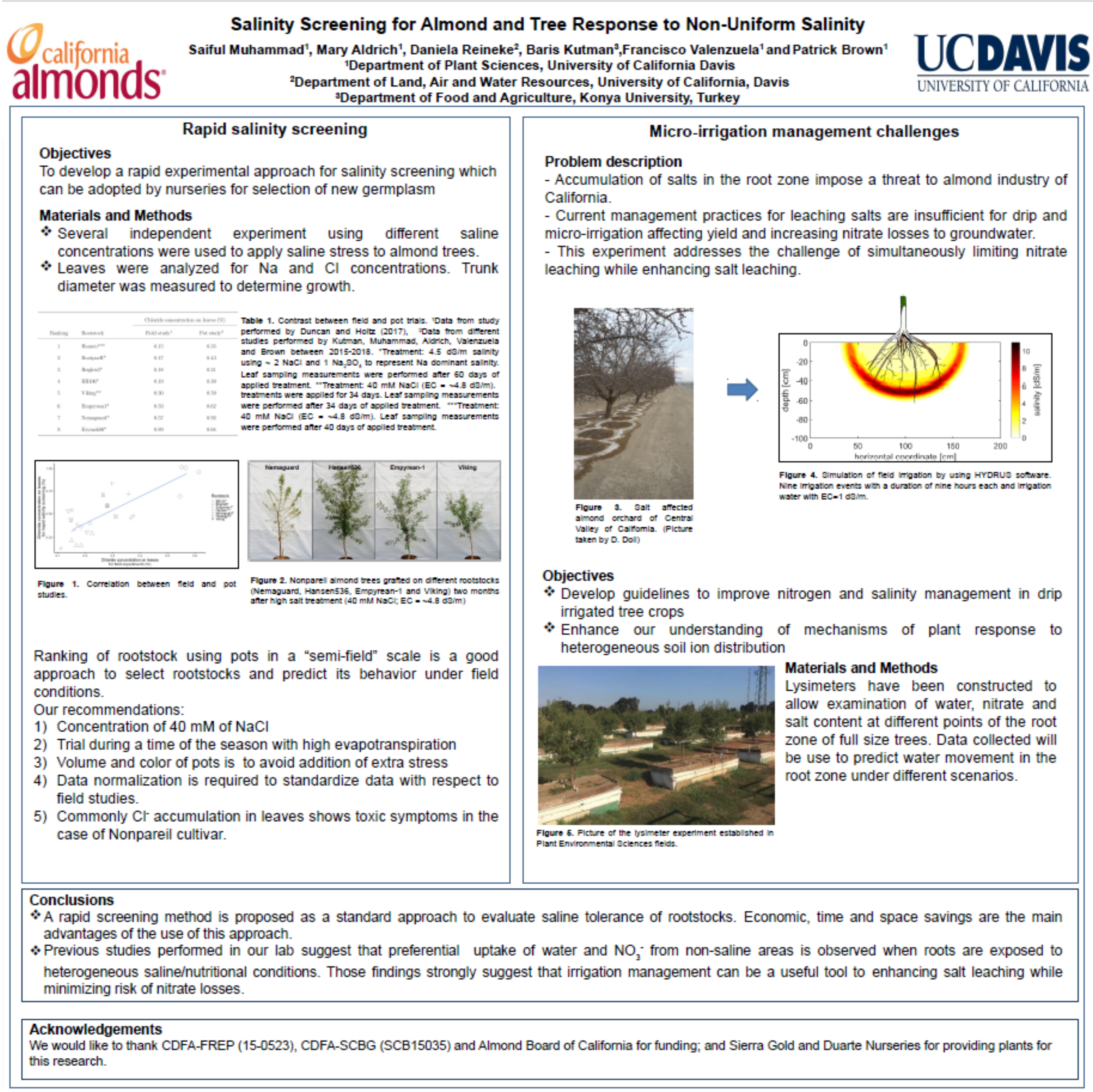

Fig. 12: Poster presented at the Almond Conference in Sacramento in December 2018.