

## 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](mailto: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*

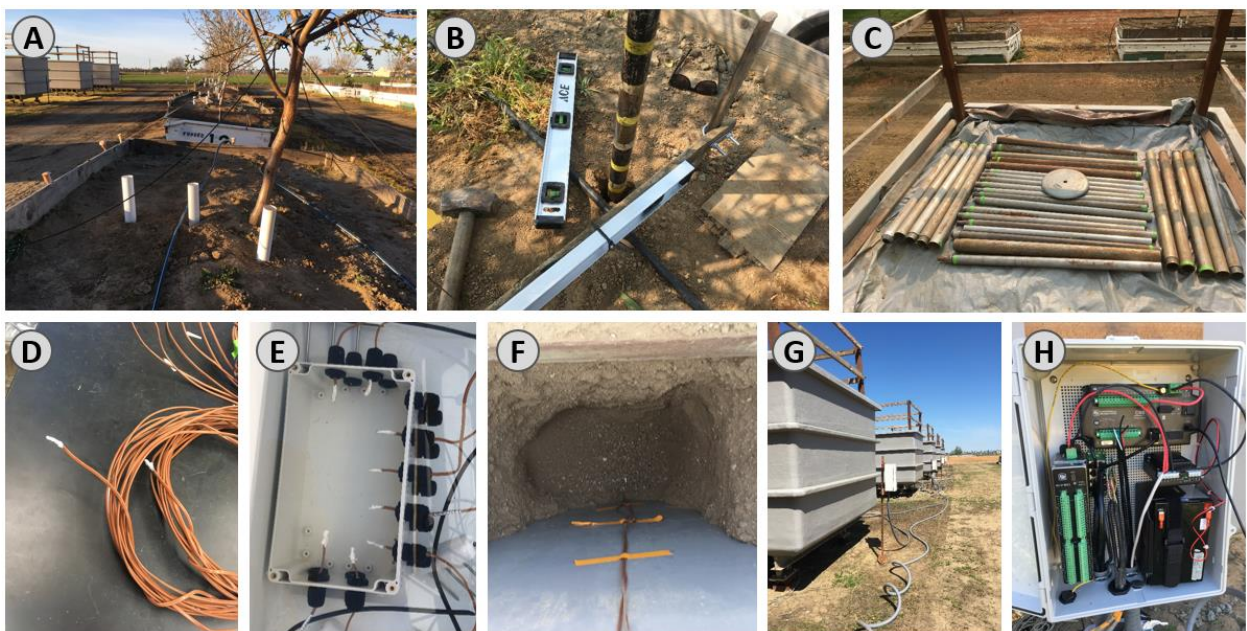
Neutron probe access tubes were installed in the tomato truck tubs by augering holes into the soil and installing PVC tubes with a plug at the lower end. There are three access tubes per tree in three of the four replicates at different distances from the tree and from the driplines (Fig. 3A). Soil samples 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



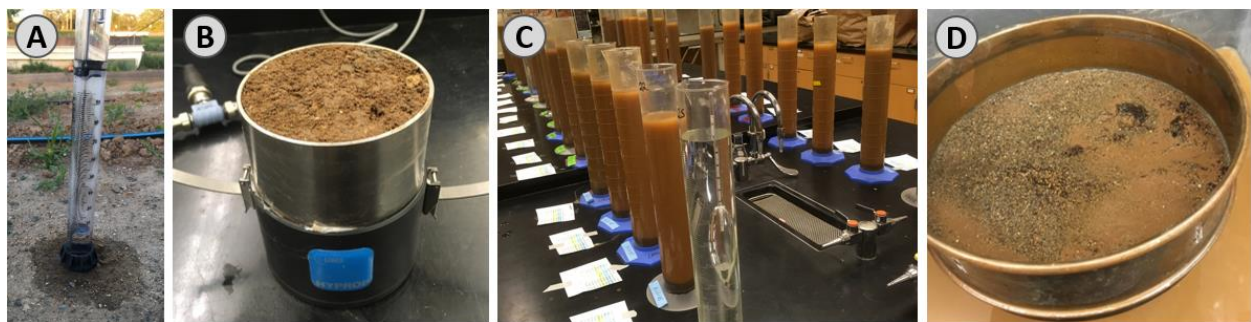
through to connect each box to the central data logger was later buried in the soil. H- Main data logger, analogue input module for measuring load cells and thermocouple outputs, battery and charge controller.

*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.

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

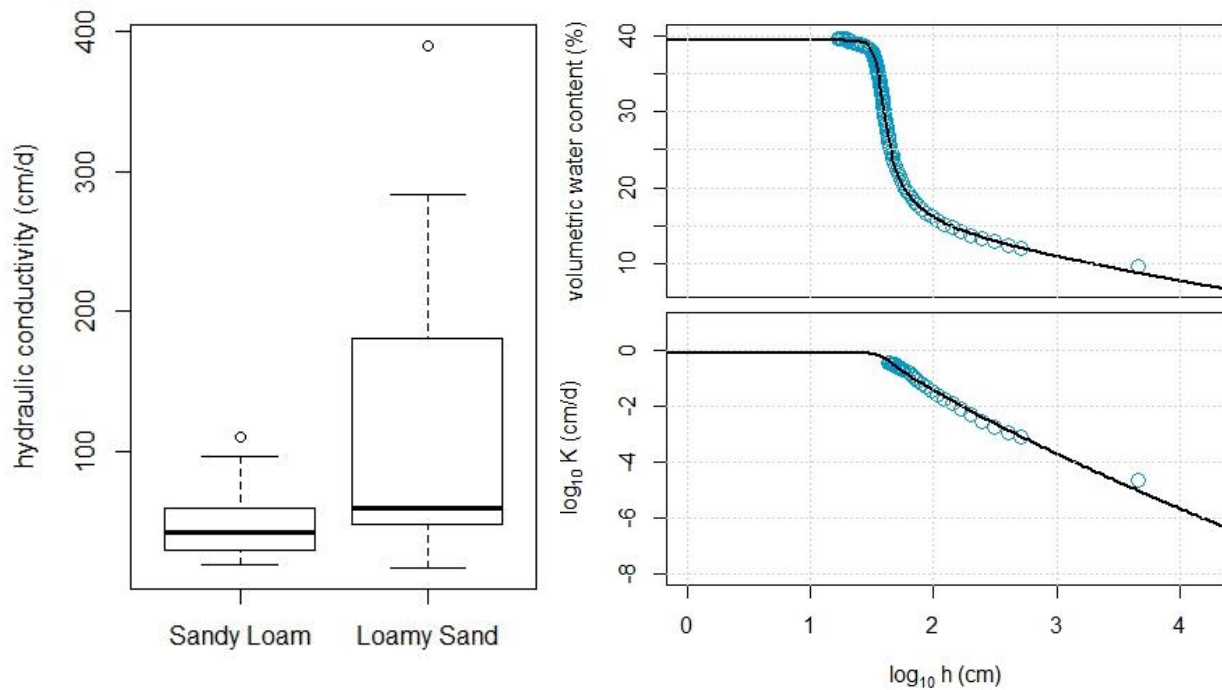


Feb March 2018	4 Field days (Yolo, Modesto, Fresno, Bakersfield) 300 attendees	Grower Field day on Nitrogen and salinity management (Integrated with CDFA – Demonstration Project)
Nov. 2018	<b>WHPHA Nutrient Conference</b> , Modesto, 150 attendees	<b>Presentation:</b> Salinity and tree crops (Dr. Patrick Brown)
Dec. 2018	<b>Almond conference</b> , Sacramento, CA (2,300 attendees)	<b>Presentation:</b> 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.



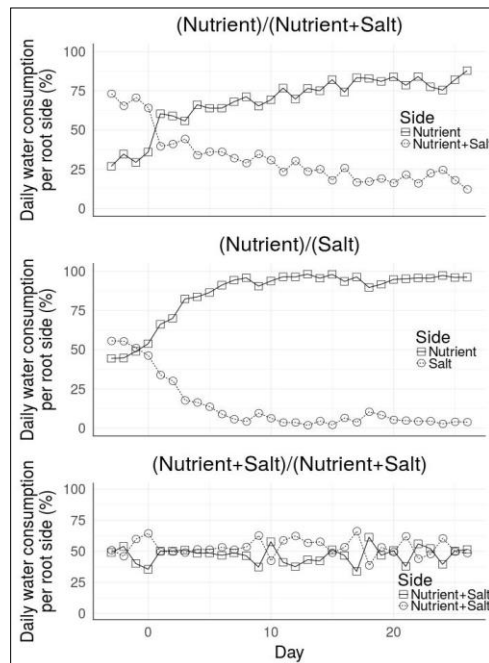
**Fig. 5:** Results of measurements of soil hydraulic properties. (a) Near saturated hydraulic conductivity for the sandy loam and the loamy sand obtained from tension disk

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.

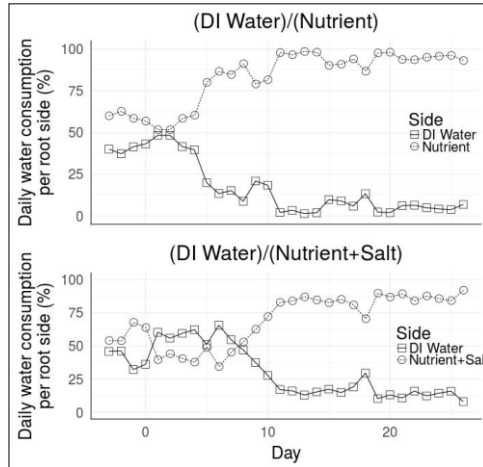
## 2. Split-root experiments

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).



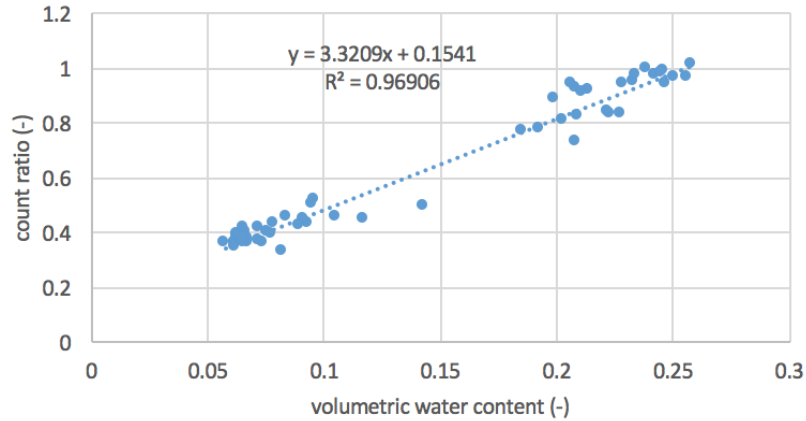
**Fig. 7:** Daily percent of water consumption from different treated root in a split root system under hydroponics of Nemaguard seedlings. [Nutrient] (0 mM NaCl; EC = ~0.6 dS/m), [DI Water] (0 mM NaCl; EC = 0 dS/m) and [Nutrient+Salt] (60 mM NaCl; EC = ~6.6 dS/m).

**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 ( $\mu\text{mol per hour}$ )
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

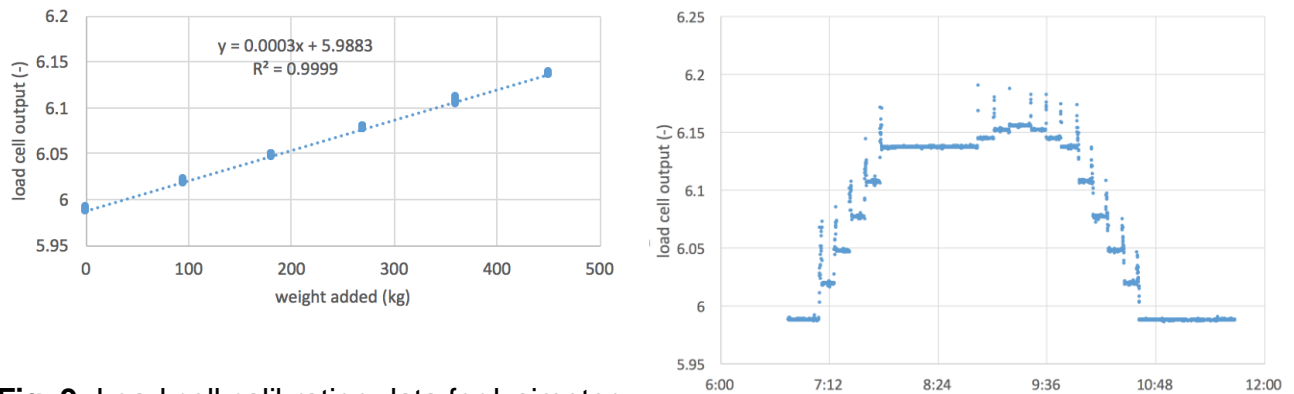
Figure 8 shows the calibration data for the loamy sand. The measurements were taken on different dates to cover a wide span in soil water content.



**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.

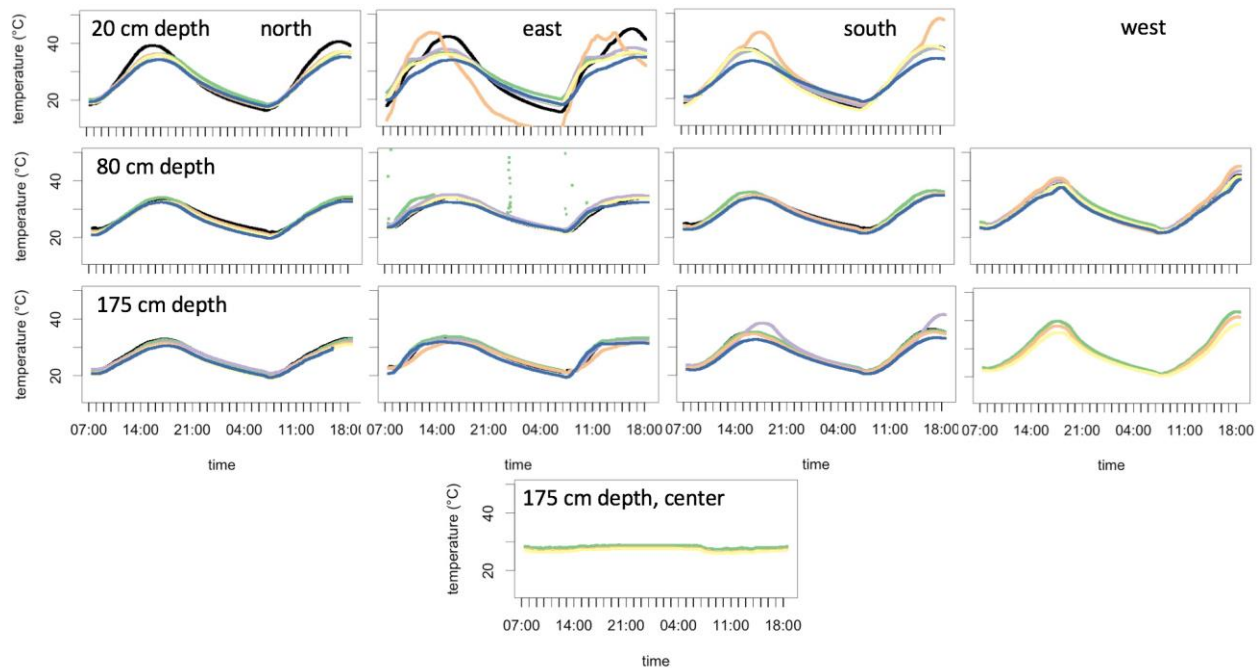


**Fig. 9:** Load cell calibration data for lysimeter 2: Calibration curve (left) and time series of load cell output during the calibration procedure (right).

#### 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 management 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.

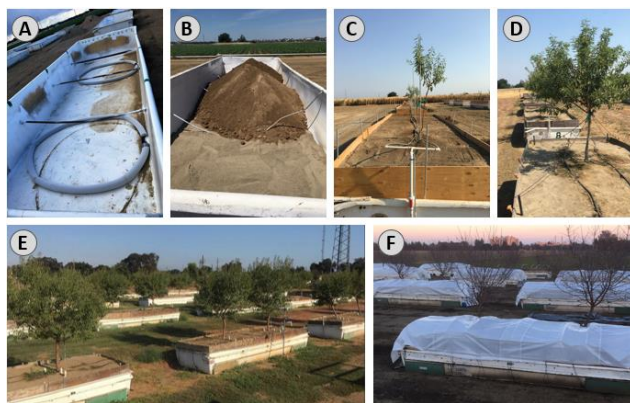
### **Introduction**

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.



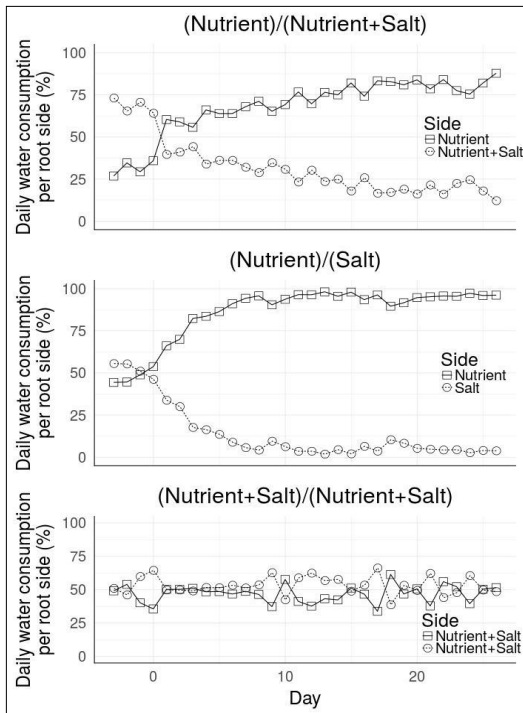
lysimeters. A- Drainage pipe covered with a screen and connected to an outlet in the wall of the tomato truck bin. B- Bin being filled with a layer of coarse sand at the bottom and loamy soil above. C- Young almond trees after transplanting into the bins. D- Trees after having grown in the bins for one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

**Fig. 1:** Construction of the 24 drainage

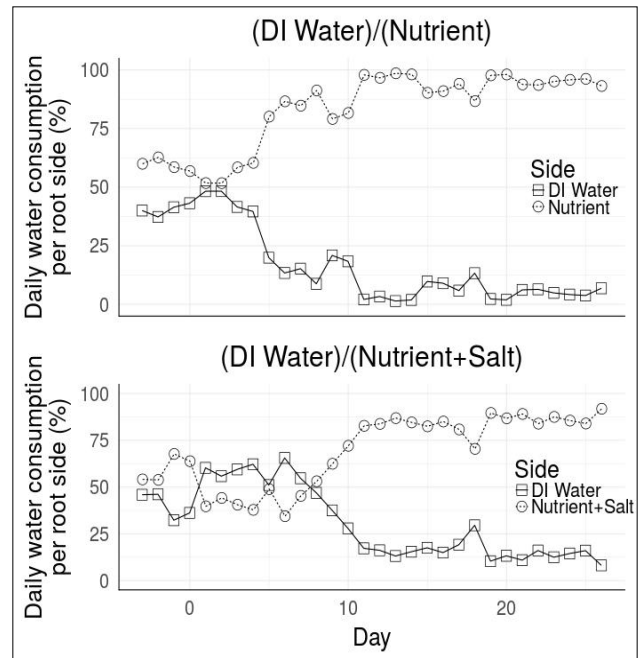
## Findings

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



## Salinity Stress in Almond, Rootstock Screening and Tree Response to Non-Uniform Salinity

Mary Aldrich<sup>1</sup>, Francisco Valenzuela<sup>1</sup>, Daniela Reineke<sup>2</sup>, Baris Kutman<sup>3</sup> and Patrick Brown<sup>1</sup>  
<sup>1</sup>Department of Plant Sciences, University of California Davis  
<sup>2</sup>Department of Land, Air and Water Resources, University of California, Davis  
<sup>3</sup>Department of Food and Agriculture, Konya University, Turkey



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### Rootstock Screening for Salinity Tolerance

**Objectives**

- To study the salinity tolerance of different almond rootstocks by monitoring tree growth and salt accumulation in leaves

**Materials and Methods**

- Two year old grafted plants of Nonpareil on different rootstocks were planted in 7 gallon pot having Calcined clay (Turface)
- Plants were irrigated with nutrient solution having all essential nutrients with salinity of ~1 ds/m
- Treatments consisted of control and 4.5 ds/m salinity using ~ 30 NaCl mM and 15 mM Na as Na<sub>2</sub>SO<sub>4</sub> to represent Na dominant salinity.
- Leaves were analyzed for Na and Cl concentration, trunk diameter was measured to determine growth

**Results**

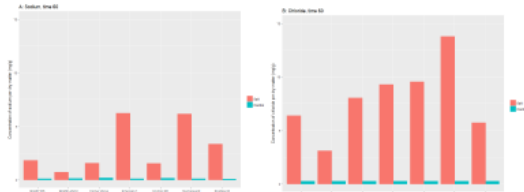


Figure 1 and 2. Leaf Na<sup>+</sup> and Cl<sup>-</sup> concentrations of Nonpareil grafted on different rootstocks. Rootstocks varied in Na<sup>+</sup> and Cl<sup>-</sup> accumulation in leaves. Empyrean 1 and Nemaguard accumulated more Na in leaves whereas Bright 106, Bright Hybrid, Corner Stone and Krymsk 86 accumulated significantly less. Leaf chloride concentrations in Nemaguard was significantly higher than all other rootstocks. One hypothesis is that Nemaguard is physiologically unable to repress salt uptake, which causes in significant salt translocation to the leaves and subsequent damage. This finding is consistent with other research.

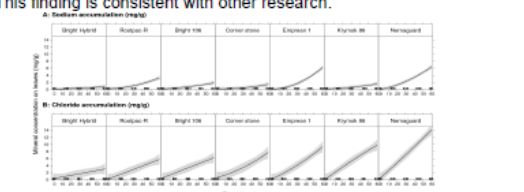


Figure 3. Salt accumulation over time with a 95% confidence interval is shown here. Results show that Nemaguard and Empyrean accumulated a significantly higher Na<sup>+</sup> and Cl<sup>-</sup> over time than other rootstocks. Caliper measurements were taken to determine tree health and growth (data not shown). All rootstocks increased in diameter in the first month, however both Nemaguard and Empyrean 1 did not increase in diameter throughout the rest of the season.

### Split-root experiment under non-uniform saline conditions

**Objectives**

- Elucidate the physiological mechanisms of root under heterogeneous saline conditions with the final goal of improving field management practices of orchard using micro-irrigation strategies.

**Materials and Methods**

- To test the effects of heterogeneous salt and nutrient distribution on plant performance non-grafted seedlings of Nemaguard were grown for 60 days then roots were divided in half and placed in a split root system that allowed for differential application of nutrients and salts to root halves.




Figure 4. Split-root experiment setup under solution culture.

**Results**

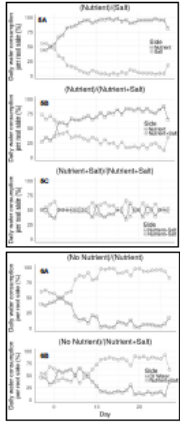


Figure 5 and 6. Percentage of water consumption per root treated subzone for non-uniform saline treatments and non-uniform nutrient/saline conditions.

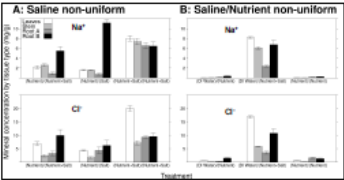


Figure 7. Sodium and chloride concentration for different tissue and different root treatments.

Almonds are remarkably plastic at early stages exhibiting a nearly complete shut-down of water consumption from the saline treated root half if a non-saline root zone was present (Figure 5A). However, if the saline root-zone contains nutrients then uptake from saline root-zone will occur (Figure 5B) demonstrating that roots will exploit saline soils if nutrients are present. (Figure 6B). In the long term (after 28 days) morphological plasticity was observed (data not presented). Non-uniform saline conditions decreased significantly the accumulation of salt in tissue (Figure 7). When nutrients are only present in the saline sub-zone, plants then strong salt uptake occurred (Figure 7). A significant decrease on salt tissue concentration under non-uniform saline conditions was observed (Figure 7); this less amount of salt accumulated on shoots improved growth performance significantly (data not presented).

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**Conclusions**

- Bright 106, Bright Hybrid and Corner Stone, and Krymsk 86 accumulated significantly less Na, while Empyrean 1 and Nemaguard accumulated more Na. Rootpac-R were intermediate in Na accumulation in leaves.
- Bright Hybrid accumulated the lowest amount of Cl, while Corner stone, Empyrean 1, and Krymsk 86 accumulated an intermediate amount and Nemaguard accumulated the highest amount.
- Diameter measurements indicate that there was rapid growth early in the season and then no growth throughout the season for the highest salt accumulator, Nemaguard.
- Substantial root plasticity and ability to restrict uptake from saline soils if nutrients are available in non-saline root zone.
- Our findings suggest that this preferential uptake of water and NO<sub>3</sub><sup>-</sup> when root are exposed to heterogeneous saline/nutritional conditions may be a useful tool to improve field management practices to limiting nitrate leaching while enhancing salt leaching in arid agricultural areas using micro-irrigation strategies.

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**Acknowledgements**

We would like to thank CDFA-FREP, CDFA-SCBG and Almond Board of California for funding; and Sierra Gold Nurseries and Duarte Nursery for providing plants for this research.

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

### Rapid salinity screening

**Objectives**  
 To develop a rapid experimental approach for salinity screening which can be adopted by nurseries for selection of new germplasm

**Materials and Methods**

- ❖ Several independent experiment using different saline concentrations were used to apply saline stress to almond trees.
- ❖ Leaves were analyzed for Na and Cl concentrations. Trunk diameter was measured to determine growth.

Ranking	Rootstock	Field (mmol/m <sup>2</sup> )	Pot (mmol/m <sup>2</sup> )
1	Nonpareil <sup>1</sup>	6.02	6.00
2	Nonpareil <sup>2</sup>	6.07	6.61
3	Nonpareil <sup>3</sup>	6.14	6.31
4	Nonpareil <sup>4</sup>	6.31	6.00
5	Nonpareil <sup>5</sup>	6.30	6.00
6	Nonpareil <sup>6</sup>	6.00	6.00
7	Nonpareil <sup>7</sup>	6.02	6.00
8	Nonpareil <sup>8</sup>	6.00	6.00

**Table 1.** Contrast between field and pot trials. <sup>1</sup>Data from study performed by Duncan and Holtz (2017). <sup>2-8</sup>Data from different studies performed by Kutman, Muhammad, Aldrich, Valenzuela and Brown between 2015-2018. <sup>1</sup>Treatment: 4.5 dS/m salinity using 2 NaCl and 1 Na<sub>2</sub>SO<sub>4</sub> to represent Na dominant salinity. Leaf sampling measurements were performed after 60 days of applied treatment. <sup>2</sup>Treatment: 40 mM NaCl (EC = ~4.8 dS/m), treatments were applied for 34 days. Leaf sampling measurements were performed after 34 days of applied treatment. <sup>3-8</sup>Treatment: 40 mM NaCl (EC = ~4.8 dS/m). Leaf sampling measurements were performed after 40 days of applied treatment.

**Figure 1.** Correlation between field and pot studies.

**Figure 2.** Nonpareil almond trees grafted on different rootstocks (Nonpareil, Hansen536, Empyrean-1 and Viking) two months after high salt treatment (40 mM NaCl; EC = ~4.8 dS/m).

Ranking of rootstock using pots in a "semi-field" scale is a good approach to select rootstocks and predict its behavior under field conditions.

Our recommendations:

- 1) Concentration of 40 mM of NaCl
- 2) Trial during a time of the season with high evapotranspiration
- 3) Volume and color of pots is to avoid addition of extra stress
- 4) Data normalization is required to standardize data with respect to field studies.
- 5) Commonly Cl<sup>-</sup> accumulation in leaves shows toxic symptoms in the case of Nonpareil cultivar.

### Micro-irrigation management challenges

**Problem description**

- Accumulation of salts in the root zone impose a threat to almond industry of California.
- Current management practices for leaching salts are insufficient for drip and micro-irrigation affecting yield and increasing nitrate losses to groundwater.
- This experiment addresses the challenge of simultaneously limiting nitrate leaching while enhancing salt leaching.

**Figure 3.** Salt affected almond orchard of Central Valley of California. (Picture taken by D. Doll)

**Figure 4.** Simulation of field irrigation by using HYDRUS software. Nine irrigation events with a duration of nine hours each and irrigation water with EC=1 dS/m.

**Objectives**

- ❖ Develop guidelines to improve nitrogen and salinity management in drip irrigated tree crops
- ❖ Enhance our understanding of mechanisms of plant response to heterogeneous soil ion distribution

**Materials and Methods**

Lysimeters have been constructed to allow examination of water, nitrate and salt content at different points of the root zone of full size trees. Data collected will be use to predict water movement in the root zone under different scenarios.

**Figure 6.** Picture of the lysimeter experiment established in Plant Environmental Sciences fields.

**Conclusions**

- ❖ A rapid screening method is proposed as a standard approach to evaluate saline tolerance of rootstocks. Economic, time and space savings are the main advantages of the use of this approach.
- ❖ Previous studies performed in our lab suggest that preferential uptake of water and NO<sub>3</sub><sup>-</sup> from non-saline areas is observed when roots are exposed to heterogeneous saline/nutritional conditions. Those findings strongly suggest that irrigation management can be a useful tool to enhancing salt leaching while minimizing risk of nitrate losses.

**Acknowledgements**  
 We would like to thank CDFA-FREP (15-0523), CDFA-SCBG (SCB15035) and Almond Board of California for funding; and Sierra Gold and Duarte Nurseries for providing plants for this research.

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