**California Department of Food and Agriculture**
**Fertilizer Research and Education Program**
**Final report**

## A. Project Information:

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

**Grant Number: 18-0549**

**Project Leader:**


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## B. Abstract:


An experiment was conducted to investigate the implications of the conclusions drawn from research conducted in previous years using a simplified system (split-root system in the greenhouse) for irrigation and fertigation management in a drip-irrigated almond orchard under saline conditions. Experiments were conducted using four-year-old almond trees grown outdoors in large (8 m long, 2.2 m wide, 1.2 m high) fiberglass bins that were exposed to three different irrigation/fertigation treatments (low frequency saline (LFS), high frequency saline (HFS), high frequency non-saline (HFNS)). It was shown that application of saline water (LFS) significantly increased leaf Cl concentration but increasing the irrigation/fertigation frequency in presence of salinity (HFS) did not significantly decrease leaf Cl concentrations. HFS and LFS did however alter leaf Cu, Zn, Fe, and Mg concentrations, indicating that irrigation/fertigation frequency may still have an impact on plant growth. The absence of an effect of irrigation/fertigation frequency on Cl may be explained by insufficient nutrient concentrations within the non-saline zone created by the drip emitters or due to a smaller than expected difference in salinity and nutrient distributions between the HFS and LFS treatments. The difference with respect to other elements between the two treatments could either be an effect of the salinity dynamics caused by the different systems or by the different irrigation frequency and therefore moisture dynamics itself. As expected, a lower salinity zone under the area wetted by the drip-emitters was observed and root abundance was higher in these areas, confirming the concept of salinity-heterogeneity under drip irrigation and illustrating the preferential exploration of non-saline zones by roots.


## C. 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 micro-irrigation 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.

## D. Objectives

**1.** To characterize patterns of root nitrate uptake and plant response when plants are grown with roots in soils heterogeneous salinity distribution (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 and Na) 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.

## E. Methods:

*E.1 Experimental design*

Almond trees of the Nonpareil variety were established from 2016 to 2018 in large tomato truck bins measuring 28 x 8 x 5 ft (L×W×D) with 2 trees at a spacing of 14 feet (Fig. 1). The experimental design was a factorial design with three factors: irrigation/fertigation treatment, rootstock (Nemaguard or Viking), and soil type (sandy loam or loamy sand). The three irrigation/fertigation treatments are a low frequency saline treatment (LFS; irrigation every 4 days and fertigation every 8 days), high frequency saline treatment (HFS; daily irrigation and fertigation) and high frequency treatment with non-saline water (HFNS, daily irrigation and fertigation without added salt). The salinity of the irrigation water in the saline treatments (HFS and LFS) was increased from 0.3 dS/m to 1.7 and 2.2 dS/m (in 2020 and 2021, respectively) by adding NaCl, $MgSO_4$, and $CaCl_2$ at a 1:2:3 molar ratio. Each treatment combination was replicated 4 times, resulting in a total of 48 trees and 24 tubs. The layout of the experiment is shown in Fig. 2.

Application of treatments started in summer 2019. It should be noted that the treatments were slightly different for the remainder of 2019 and were only changed to their final treatments at the beginning of 2020. Initially, the three treatments were daily irrigation (T1, now HFS), irrigation every two days (T2, now HFNS), and irrigation every 3 days (T3, now LFS). More details on the treatments in 2019 and data collected during this initial period can be found in section L.1.

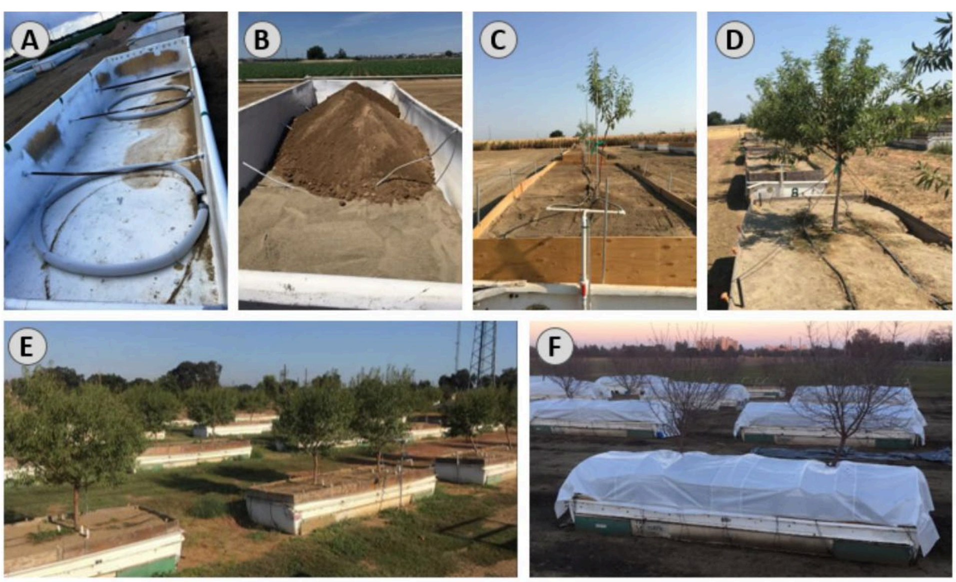



***Fig. 1:*** *Construction of the 24 drainage lysimeters. A- Drainage pipe covered with a screen and connected to an outlet in the wall of the tomato truck bin. B- Bin being filled with a layer of coarse sand at the bottom and loamy soil above. C- Young*

*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.*

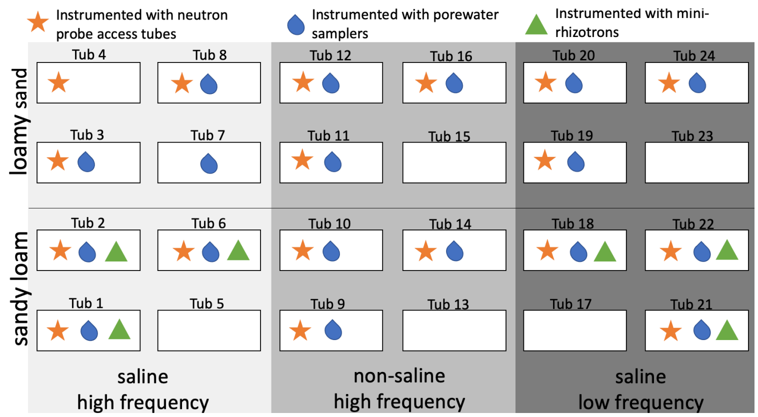



***Fig. 2:*** *Layout of tubs, treatments, and instrumentation. No instrumentation was installed in Tub 17 and no porewater samplers were installed in Tub 4 due to a broken wall and a fallen tree, respectively. Instrumentation of Tubs 21 and 7 compensates for this.*

## *E.2 Characterization of soil properties*

Four undisturbed samples were taken in December 2019 and analyzed for water retention curve and unsaturated hydraulic conductivity curve using the HYPROP device (METER Group, Inc., Pullman, WA; Fig. 3B). The data of the four replicates were pooled for each soil and the PDI model of water retention (Iden and Durner, 2014) using the Fredlund and Xing model (Fredlund and Xing, 1994) to describe capillary water retention was fitted to the data in order to obtain soil hydraulic parameters. The undisturbed samples were also used to calculate bulk density by dividing the oven dry weight of the sample by the known sample volume. Porosity of the soil was calculated by assuming a density of the solid particles of 2.5 g $cm^{-3}$.

Measurements of saturated soil hydraulic conductivity were taken in-situ using a tension disk infiltrometer (Meter Group, Inc., Pullman, WA; Fig. 3A). Measurements were taken at twelve different locations for each soil type. Soil texture of 36 samples per soil type was determined using the hydrometer method and wet sieving (Fig. 3C and Fig. 3D).

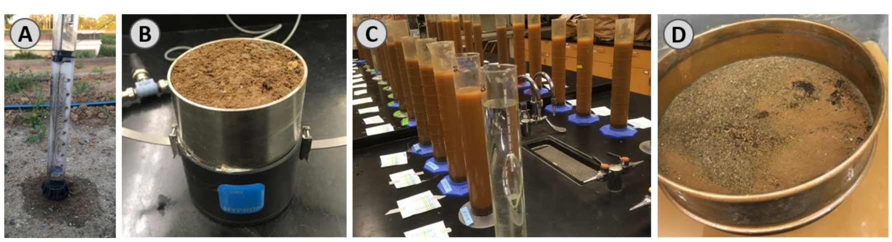



***Fig. 3:*** *Measurement of soil properties. A- Measuring near saturated hydraulic conductivity in the field using a tension disk infiltrometer. B- Measuring retention curve and unsaturated hydraulic conductivity curve of undisturbed soil samples using the HYPROP device. C- Texture analysis using the hydrometer method. D- Determining the mass of the sand fraction by wet sieving.*

One sample from each soil type was taken at the beginning of the experiment and submitted to the UC Davis Analytical lab for analysis of chemical properties, including electrical conductivity of the saturated paste extract, pH, and element concentrations.

*E.3 Instrumentation*

The bins were instrumented with neutron probe access tubes, pore water samplers and mini-rhizotron access tubes (Fig. 5). Each instrument type was installed in only a subset of tubs/trees (Fig. 2). The positions of the instruments within the tub are shown in Fig. 4 for a tub that has all three instrument types.

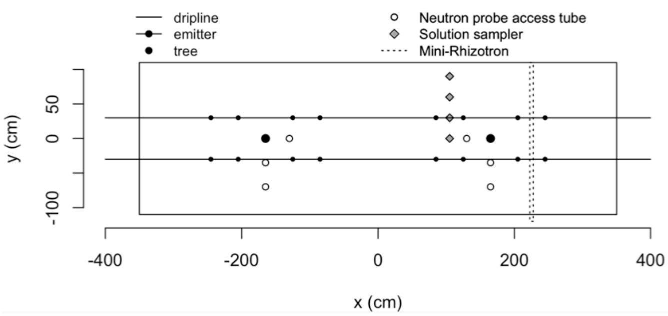



***Fig. 4:*** *Schematic drawing of the instrumentation in the drainage lysimeters. Pore water samples are taken at 10, 25, 45 and 80 cm depth and neutron probe measurements at 15, 25, 35, 45, 60 and 75 cm depth. Mini-rhizotron access tubes are installed at 30 cm and 80 cm depth. Not all of the instrumentation is present in every lysimeter.*

***Fig. 5:*** *Instrumentation of the bins: Left: Neutron probe access tubes, right: Porewater samplers.*

*E.4 Soil sampling*

Soil samples were taken from treatments HFS and LFS (Viking and sandy loam treatments only) in October 2020. Fifteen samples from 0-30 cm depth were taken from the rootzone of three trees in each of the two treatments (HFS, LFS) along a cross-section across the width of the tub (**Fig. 6**) using a 30 cm long auger drill bit. After removing the auger drill bit from the hole, the soil on the auger bit was divided into sections from 0-10 cm, 10-20 cm and 20-30 cm depth. The electrical conductivity (EC) of the 1:2 soil-water extract of each sample was measured in the laboratory. The EC of the 1:2 soil-water extract was converted to the EC of the saturated paste extract using a relationship previously measured in the laboratory using the same soil. Roots were separated from the soil by passing the soil-water suspension through a No. 35 sieve and manually sorting the material remaining in the sieve using tweezers and pipettes. Root fragments were then distributed on a sheet of paper while still wet and scanned using a document scanner. A relative root abundance was derived as the logarithm of the size (in number of pixels) of the area that was classified as “root” using a K-means classification approach.

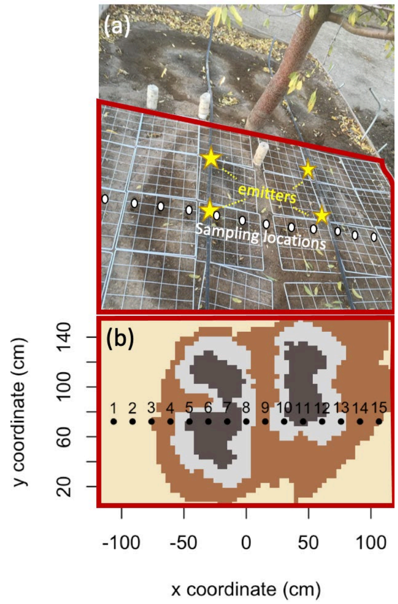


***Fig. 6:*** *Soil sampling locations. (a) Photograph of the sampled surface area in tub 22 (LFS, Viking, sandy loam). (b) Sampled area as a soil color map illustrating the areas wetted by the drip emitters (areas that are flooded during irrigation in dark grey) and the location of the 15 soil samples.*

*E.5 Leaf sampling*

Leaf samples were taken in all treatments in June and August 2020 and in June and September 2021. One sample per tree was taken and leaves were sampled from about 15 non-fruiting spurs distributed around the tree at about 1.5 meters height. After transferring to the laboratory in ice-filled coolers, the leaves were washed, dried at 60°C and ground. The samples were then sent to the UC Davis Analytical lab and analyzed for N, P, K, S, B, Ca, Mg, Zn, Mn, Fe, Cu and Cl. Differences between treatment were tested by means of ANOVA for each element separately.

E.8 Porewater sampling

Tension was applied (ca. 80cbar) to the porewater samplers in the afternoon the day before samples were taken with a vacuum pump. On the day of sampling, porewater was transferred from the samplers into 15 ml falcon tubes which were stored in an ice-filled cooler until they were taken to the laboratory for EC and nitrate analysis.

*E.9 Drainage water collection*

Drainage water was collected outside of the tubs in plastic bags or plastic tubs and the drainage water volume was measured either by measuring the height of the water level in the plastic tub or by using a 2 L measuring cylinder to measure the volume of the water in the plastic bag. When drainage water was sampled for analysis of EC or nitrate concentration, the sample was taken directly from the water flowing out of the drainage tube before it reached the plastic tub or plastic bag.

E.10 Modeling

Water and solute transport (EC) in the drainage lysimeters was simulated in the period from March 15 to August 29 was simulated in 3D using the HYDRUS software (Fig. 7). Treatments with different irrigation frequencies were simulated (I0: Irrigation is split into several applications per day, trying to match ET as close as possible; I1: Irrigation interval 1 day (one single application per day); I3: Single irrigation every 3 days; I6: Single irrigation every 6 days). The simulated domain and boundary conditions are shown in Fig. 7. The simulation assumes reductions in water uptake when water and/or salt stress occur. Treatments were compared with respect to the spatial and temporal patterns of salinity.

## F. Data/results

### *F.1 Characterization of the soils*

#### *F.1.1 Soil physical properties*

Compared to the sandy loam, the loamy sand is characterized by a higher saturated hydraulic conductivity and a greater variability in saturated hydraulic conductivity between replicates (Fig. 8). The loamy sand loses water more rapidly with increasing tension and the sandy loam holds more water in the dry range (Fig. 8). The sandy loam also has a higher bulk density, higher water holding capacity, and higher plant available water capacity (Tab. 1).

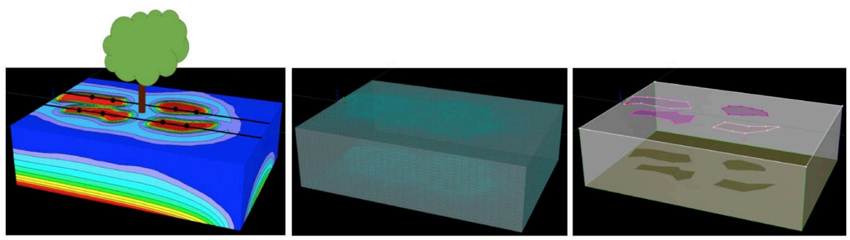


***Fig. 7:*** *Simulated domain. Left: Image illustrating the relative positions of the tree and the drip emitters; middle: finite element mesh; right: locations of the variable flux (pink) and seepage face (green) boundary conditions.*

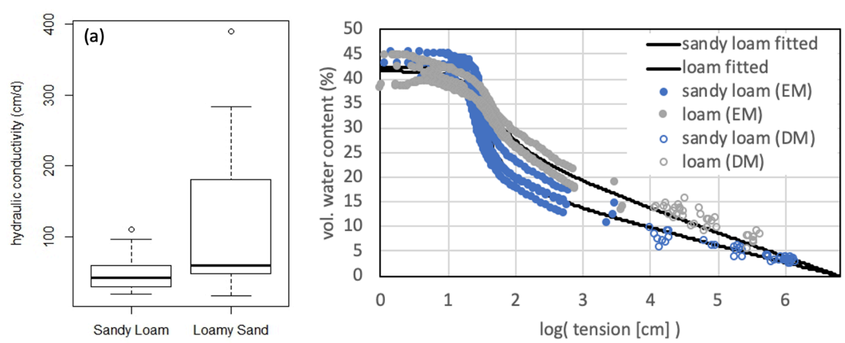



***Fig. 8:*** *Left: Near saturated hydraulic conductivity for the sandy loam and the loamy sand obtained from tension disk infiltrometer measurements. Right: Retention curves of the two soil types measured in the laboratory using a combination of the evaporation method (EM; four undisturbed 250 cm³ samples per soil type) and the dewpoint method (DM; 48 samples per soil type).*

***Tab. 1:*** *Physical properties of the two soil types: Texture, porosity, water holding capacity (WHC), plant available water holding capacity (PAWC), and saturated hydraulic conductivity (Ksat). The texture classification based on the sand, silt and clay percentages measured using the hydrometer methods (loam and sandy loam) deviates from the initial classification of the two soils as sandy loam and loamy sand. To avoid confusion, the soils will be continued to be referred to as sandy loam and loamy sand.*

| Property | Loam | Sandy loam |
|---|---|---|
| % Sand, silt, clay | 50, 36, 14 | 62, 32, 6 |
| Bulk density (g $cm^{-3}$) | 1.42 ± 0.03 | 1.38 ± 0.03 |
| Porosity (%) | 46 ± 1 | 48 ± 1 |
| WHC (%) | 21 ± 1 | 17 ± 1 |
| PAWC (%) | 8.9 ± 0.6 | 6.6 ± 0.4 |
| Ksat (cm $d^{-1}$) | 43 | 60 |

### *F.1.2 Soil chemical properties*

In comparison to the loamy sand, the sandy loam is characterized by a higher initial electrical conductivity, lower pH, and higher concentrations of Ca, Mg, Cl, B, Zn, Mn, Cu while the loamy sand has a higher Fe concentration (Tab. 2).

***Tab. 2:*** *Chemical properties of the properties of the two soils used at the start of the experiment measured by the UC Davis Analytical Lab.*

| Soil | pH | EC (dS/m) | Ca (meq/L) | Mg (meq/L) | Na (meq/L) | Cl (meq/L) |
|---|---|---|---|---|---|---|
| loamy sand | 7.74 | 0.95 | 4.14 | 3.05 | 2.35 | 2.43 |
| sandy loam | 7.45 | 1.41 | 6.69 | 4.60 | 2.27 | 6.42 |

| Soil | B (mg/L) | Zn (ppm) | Mn (ppm) | Cu (ppm) | Fe (ppm) |
|---|---|---|---|---|---|
| loamy sand | 0.06 | 1.15 | 122.50 | 0.95 | 347.50 |
| sandy loam | 0.07 | 2.30 | 175.50 | 1.65 | 308.00 |

## *F.3 Rootzone observations*

The results of the soil sample analysis so far show that as expected, a low-salinity zone appears under the area wetted by the drip emitter (located close to samples 6 and 12) in both the HFS and the LFS treatments (Fig. 9). In this zone, the soil salinity is mostly between 1.5 dS/m and 2 dS/m, which is close to the irrigation water salinity. Higher salinities were observed in the middle between the driplines and at the edges of the wetted area, where soil salinity can reach values exceeding 10 dS/m. This means that a low salinity zone, from which roots could preferentially take up water to avoid the salt, does indeed exist and the conditions may therefore be similar to the ones simulated in the split-root experiment, where only a part of the root system is exposed to saline conditions. Since the spatial patterns of root density and salinity reflect the location of the wetted area at the surface of the soil, but the locations and shapes of the wetted areas are different for each tree, it is important to take the locations of the wetted areas into account when interpreting the data or using them to calibrate a model.

The root concentrations in the soil samples show that, as expected, roots preferentially explore the zone under the wetted area and root concentrations drop off towards the margins of the wetted area. Root abundance is particularly high right under the drip emitter (samples 6 and 12). Surprisingly, there was little reduction in root concentration in the middle between the two wetted areas (samples 9 and 10) despite high salinity in this region. This suggests that additional factors, such as soil moisture or nutrient availability, played a role in creating this distribution pattern.

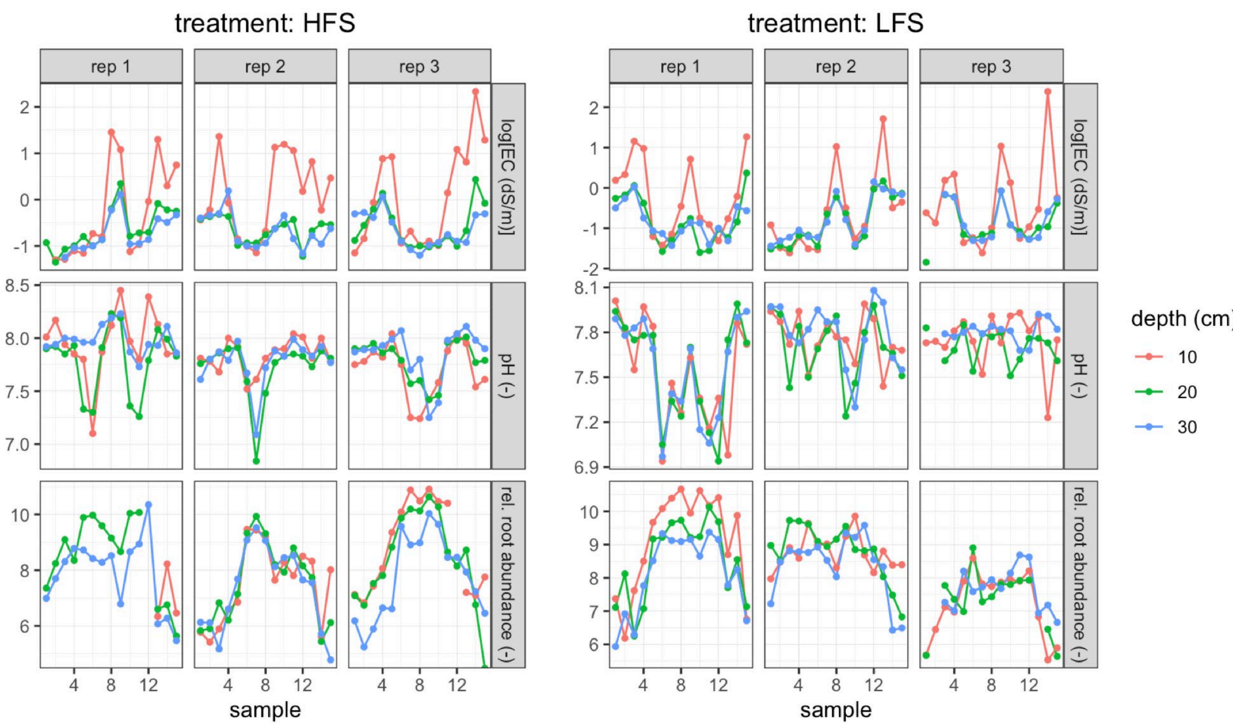



***Fig. 9:*** *Parameters of soil samples taken along a cross section perpendicular to the dripline in November 2020. Electrical conductivity (EC) of the saturated paste extract, pH, and relative root abundance at 0-10 cm and 10-20 cm depth.*

## *F.4 Plant response*

The irrigation/fertigation treatment had a significant effect on leaf Mg, Zn, Fe, Cu and Cl concentrations (Fig. 11, Fig. 12) but not on leaf N, P, K, S, B, Ca or Mn concentrations. Chloride concentrations differed significantly by rootstock, soil, and irrigation treatment. Chloride concentrations were lower for the Viking rootstock than for the Nemaguard rootstock and lower for the sand than for the loam soil. The application of saline water markedly increased leaf Cl concentrations in the saline treatments. The difference between the HFS and LFS treatments with respect to Cl is, however, not significant. Compared to the LFS treatment, the HFS treatment is characterized by overall higher concentrations of Zn and Cu, and lower concentrations of Mg (for Nemaguard).

Despite clear differences in leaf element concentrations, no significant difference in growth between the treatments were observed that could be attributed to the treatments (Fig. 10). Although mean trunk diameter differs between treatments, these differences seem to have existed before the start of the treatments and are probably due to the different locations of the treatments in the field, which are associated with differences in pest exposure, wind, and moisture. In addition, uptake of nitrogen was apparently unaffected by salinity as no significant difference in leaf nitrogen was found between the saline and non-saline treatments.

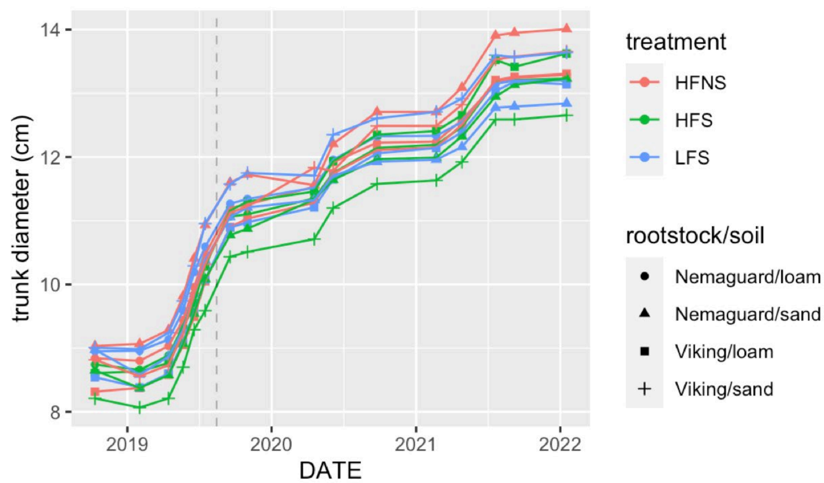



***Fig. 10:*** *Average trunk diameter in the different treatment combinations (each mean is based on four trees) over the course of the experiment. The start of the irrigation/fertigation treatment application (HFNS, HFS, LFS) is denoted by the dashed vertical line.*

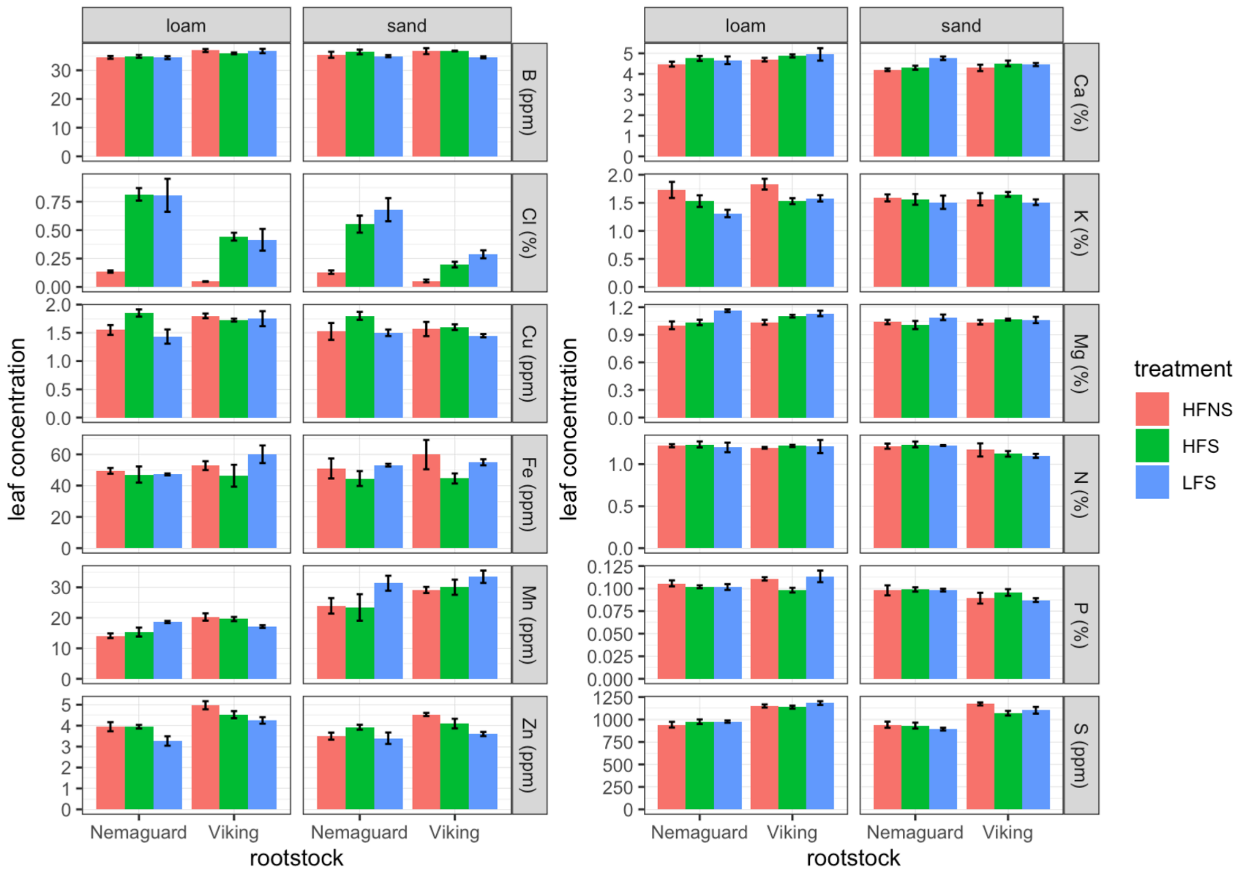



***Fig. 11:*** *Leaf element concentrations in August 2020 for the different irrigation/fertigation treatments (HFS: high frequency, HFNS: high frequency, low salinity, LFS: low frequency), rootstocks and soil types (sandy loam and loamy sand).*

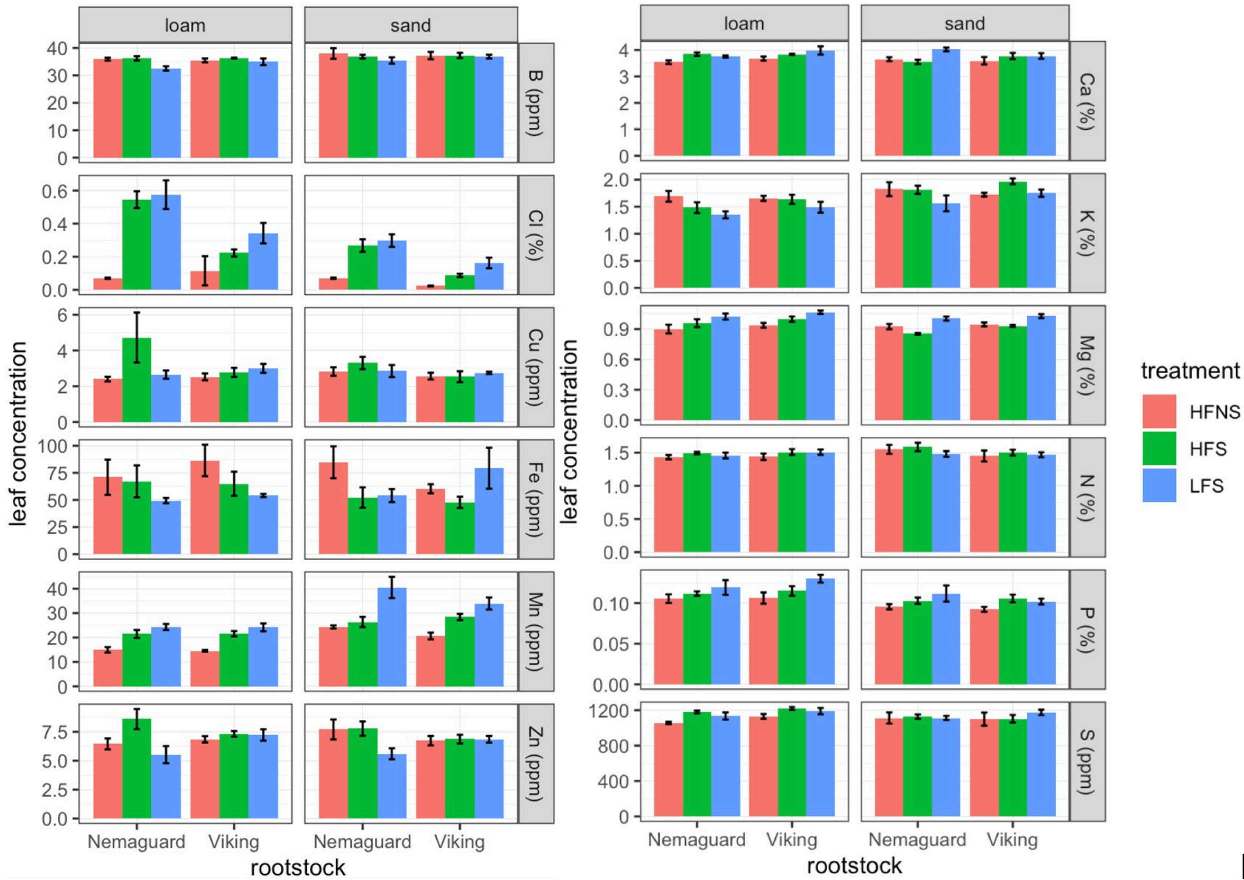



***Fig. 12:*** *Leaf element concentrations in June 2021 for the different irrigation/fertigation treatments (HFS: high frequency, HFNS: high frequency, low salinity, LFS: low frequency), rootstocks and soil types (sandy loam and loamy sand).*

## *F.5 Modeling*

Fig. 13 shows the development over time of the spatial patterns of volumetric water content, soil solution EC and root water uptake using the simulation for the hypothetical treatment I0 (several irrigation events per day) as an example. Volumetric water content is locally high in the vicinity of the drip emitters but also accumulates at the bottom over time due to the lower boundary conditions restricting drainage. Soil solution EC increases over time. First, the high salinity zone is located only around the area wetted by the drip emitters, then it extends more and more until only the zone underneath the drip emitters is relatively low in salinity. Root water uptake initially occurs in the whole domain, then gets more and more restricted to the wetter bottom part of the lysimeter and the area around the drip emitters. Finally, the saline zone expands to the bottom of the lysimeter so that root water uptake only occurs in the zone underneath the drip emitters.

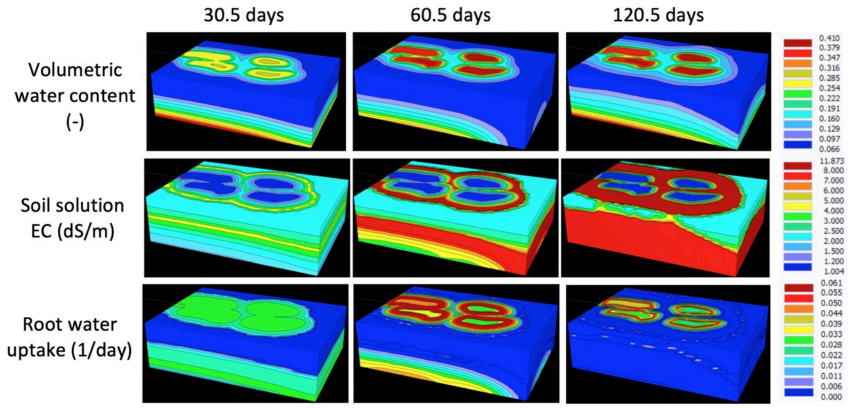



***Fig. 13:*** *Spatial distributions of volumetric water content, soil solution EC and root water uptake at times 30.5 days, 60.5 days and 120.5 days (corresponds to noon) for the treatment I0 (several irrigation events per day). The initial EC of the soil solution was 1.5 dS/m (uniformly).*

Fig. 14 shows the temporal dynamics of porewater EC at 16 different locations in the rootzone within a six-day period for irrigation intervals of 1 day, 3 days, and 6 days. According to the simulation, values of salinity are very similar between the treatments 1 day after irrigating all treatments (day 2), with both salinities in the low range (lower than 3 dS/m) and salinities in the very high range (greater than 8 dS/m). However, it can be seen that in the I3 and I6 treatments, the values in the very low range vanish between irrigations, especially for the 6-day irrigation interval I6. This may increase the plant's exposure to salinity during these times especially considering that root activity may be highest in the low-salinity zone.

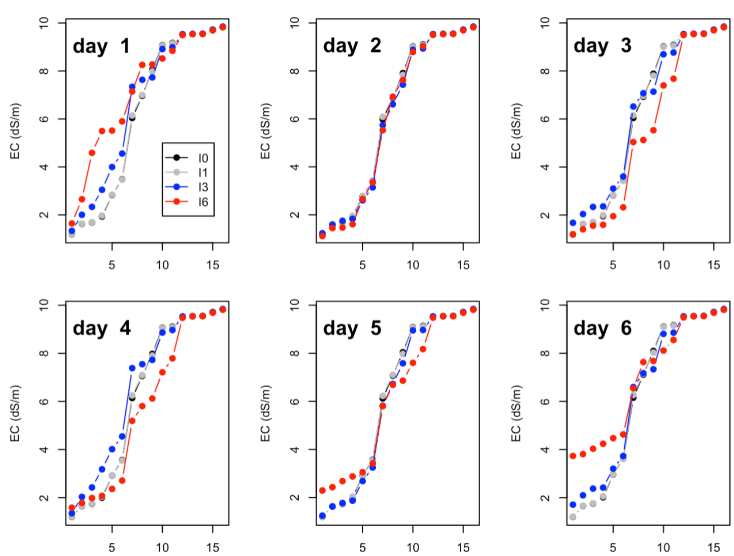



***Fig. 14:*** *Simulated soil solution EC at the 16 solution sampler locations ordered from lowest to highest on six consecutive days (days 162 to 167 at noon) for original scenario. On day one, all of the intervals were irrigated. For this scenario, except for two of the datapoints shown, salt stress was the only uptake limiting factor so that the EC distribution directly translates into the uptake distribution given the linear relation between uptake reduction and salinity in the threshold model.*

### *F.6 Development of a Web Application to manage nitrogen fertigation*

A web application has been developed that shows the simulated moisture and nitrate distribution in the rootzone under drip or microsprinkler irrigation after a single irrigation event. The user can select from a variety of irrigation and fertigation timing options (e.g., applying nitrate as a pulse at a certain time during the irrigation event vs. continuous application throughout the irrigation event).

This simulation does not account for root uptake during the irrigation event (it is assumed that the amount of application is a lot bigger than what the tree can take up immediately) or preferential flow through macropores, but it gives a rough estimate of the extent of the wetted volume and the location of nitrate rich zones and how the result differs between soil types (Fig. 15).

Available soil options include both specific soil types with corresponding hydraulic properties determined from percentages of sand, silt, and clay using a neural network model as well as typical profiles of California soil series that consist of several soil horizons with different textures.

The app can be found on this website: [https://phbrown.ucdavis.edu/development-tools-manage-nitrogen-fertigation](https://phbrown.ucdavis.edu/development-tools-manage-nitrogen-fertigation).

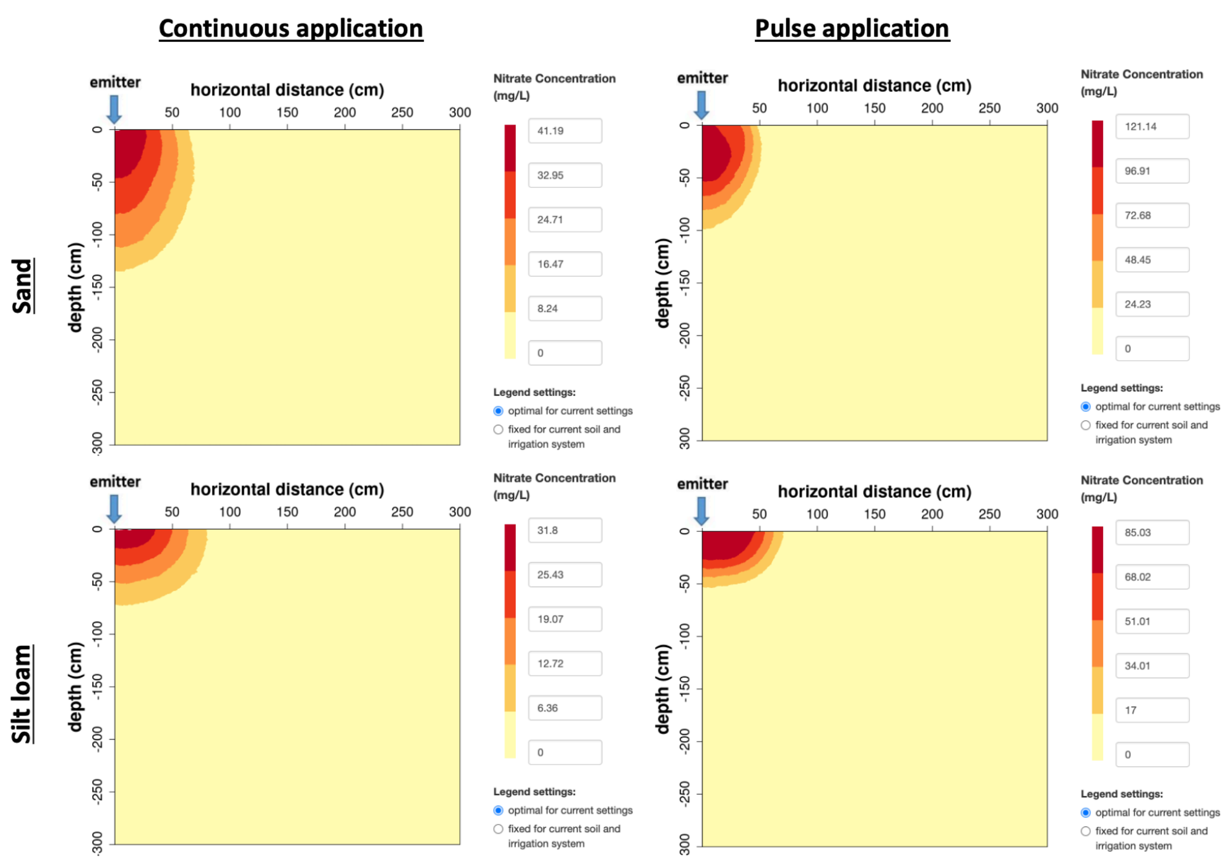



***Fig. 15:*** *Comparison of simulated nitrate distributions in the rootzone after and irrigation event for different soils and nitrate application options using the web application. Whereas for continuous application nitrate was applied throughout the irrigation event, for pulse application, nitrate was applied as a pulse towards the end of the irrigation event.*

## G. Discussion and Conclusions

In this study, three irrigation/fertigation treatments for almonds grown under drip-irrigation were compared with respect to developing spatial patterns of salinity in the rootzone, leaf element concentrations, and tree growth. The treatments differ in irrigation and fertigation frequency (HFS vs. LFS) and the level of irrigation water salinity (HFS vs. HFNS).

Increased leaf Cl concentrations in the saline treatments (HFS and LFS) compared to the non-saline treatment (HFNS) indicates that increased irrigation water salinity resulted in increased uptake of Cl and accumulation in leaves which may result in decreased tree growth and yield in the long term. The high frequency irrigation/fertigation frequency approach (HFS) did not reduce Cl concentrations relative to the low frequency approach (LFS) in this case, which is in contrast to our hypothesis that a high frequency system will reduce Cl uptake by helping to sustain a zone of low chloride levels, and sufficient nutrient concentrations and moisture that allows the tree to reduce root activity in high-chloride zones. However, as has been shown in the greenhouse experiments, nutrient distribution in the soil is another important factor determining the spatial distribution of root activity and the management approach chosen may not have been sufficient to retain enough nutrients in the non-saline zone. Another possible explanation of the lack of an effect of irrigation/fertigation frequency on leaf Cl concentrations may be that the spatial distributions of salinity within the rootzone may not have been as different between LFS and HFS as was originally expected.

No effects of irrigation/fertigation treatment on growth (stem diameter) or nitrogen status were observed. However, the different treatments resulted in significant differences in micronutrient concentrations (Mg, Zn, Fe, Cu). It is possible that these differences would affect the growth of the trees in the long term. When adjusting the irrigation frequency to gain benefits in terms of nitrate or salinity management it is therefore important to consider that the different moisture dynamics might also lead to changes in micronutrient availability and uptake.

Modeling water flow and salt transport showed that the model was capable of predicting some of the observations in the field experiment (e.g., areas of salt accumulation). However, the model output depends on the root uptake parameters chosen. Calibrating the model with the measured data and implementing a model describing the relationship between soil conditions and leaf concentrations will be the next steps to determine whether it could be possible to predict plant performance for unknown management scenarios.

## H. Challenges

Challenges in this project included the difficulty of obtaining porewater samples resulting in many missing samples, the difficulty of setup and instrumentation of the tub, the loss of two trees due to windfall and the difficulty of obtaining yield data due to squirrel damage.

## I. Project Impacts

Results were shared during the almond board of California conference in 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. The last ABC conference had 3,900 attendees gathering growers, processors, suppliers, distributors, marketers and researchers from around the globe. Since a 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.

## J. Outreach activity summary

Outreach events are listed in (Tab. 3). In addition, a web application was developed to demonstrate the effect of irrigation and fertilizer injection timing on the distribution patterns of nitrate and soil moisture in the root zone and was published on the lab's website (https://phbrown.ucdavis.edu/development-tools-manage-nitrogen-fertigation). The tool shows results of simulating a single irrigation event on a moderately dry soil (Fig. 25). Simulations do not account for water or nutrient uptake of roots and evaporation from the soil surface and were done using the software HYDRUS 2D/3D (Šimunek et al., 2012), which numerically simulates the movement of water and solutes under unsaturated conditions in soils.

***Tab. 3:*** *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)<br>**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 | **Presentation**: Nitrogen and salinity management in almonds (Dr. Patrick Brown)<br>**Poster:** Salinity Screening for Almond and Tree Response to Non-Uniform Salinity (Dr. Francisco Valenzuela-Acevedo) |
| Dec. 2019 | **Almond conference**, Sacramento, CA | **Poster:** Physiology and Management of Salinity Stress and Nitrate Leaching in almond (Dr. Francisco Valenzuela and Daniela Reineke). |
| Oct. 2020 | **FREP/WPHA conference** Online, over 200 participants | **Presentation:** Improving nitrate and salinity (Daniela Reineke) management strategies for almond grown under micro-irrigation |
| Feb. 2021 | **Cal Agronomy Society Plant and Soil Conference** Online, 125 participants | |
| Feb./March 2021 | **"Training Tuesdays" hosted by the Almond Board of California** | **Presentations:**<br>(1) Groundwater Recharge: The Why and the How<br>(2) Nitrogen Best Management Practices |

| | | |
|---|---|---|
| | (1) 335 participants, (2) 351 participants | |
| March 2021 | **Pomology Extension Conference**<br>Online, 25 participants | **Presentation:** Update on Nutritional Challenges in Almond |
| June 2021 | **Event Name: International Symposium on Mineral Nutrition of Fruit Crops**<br>Online, 525 participants | **Presentations:**<br>(1) Nitrogen regulations and changes in California agriculture - a case study (Patrick H. Brown)<br>(2) Heterogeneous saline and nutritional conditions in the root-zone and its effect in water and nutrient uptake (Francisco Valenzuela-Acevedo)<br>(3) Panel discussion I: Management of N and P to Meet Regulatory Requirements and Environmental Protection (Patrick H. Brown) |

## K. References


Fredlund, D. G., & Xing, A. (1994). Equations for the soil-water characteristic curve. Canadian geotechnical journal, 31(4), 521-532.

Iden, S. C., & Durner, W. (2014). Comment on “Simple consistent models for water retention and hydraulic conductivity in the complete moisture range” by A. Peters. Water Resources Research, 50(9), 7530-7534.

Šimunek, J., Van Genuchten, M. T., & Šejna, M. (2012). HYDRUS: Model use, calibration, and validation. Transactions of the ASABE, 55(4), 1263-1274.


## L. Appendix

### L.1 Data from a measuring period in September/October 2019

From 09/26/2019 to 10/02/2019 measurements of soil moisture, stem water potential, drainage volume, electrical conductivity and nitrate concentrations of the soil solution were taken daily in the lysimeter experiment (drainage lysimeters with sandy loam, only). This report summarizes the data collected during this period in order to Observe the temporal dynamics of the system within one irrigation cycle, the accumulation of salt over the course of a week and to monitor the movement of a nitrate pulse that was injected into the irrigation water on 09/26/2019 through the root zone.

Three different irrigation treatments were applied (Fig. 1), with four lysimeters and eight trees in each treatment: Daily irrigation (T1), irrigation every 2 days (T2), irrigation every three days (T3). The average irrigation volume per day was the same (e.g., the irrigation duration for T1 was three times longer than for T3. The measuring period was chosen so that all treatments were irrigated on the first day (09/26/2019). Also, a single nitrate pulse was injected for four hours (7:15 am to 11:15 am) on 09/26/2019.

## Meteorology, irrigation and drainage

Meteorological data, including reference evapotranspiration (ET0) were obtained from the CIMIS station in Davis (California Department of Water Resources, 2019). Crop coefficients (Kc) were derived for each day by linearly interpolating monthly values from the literature. Hourly values of the baseline stem water potential were derived using hourly temperature and relative humidity from the CIMIS data and by interpolating published values of baseline stem water for almond and prune for specific temperatures and relative humidities (Fulton, 2018). Irrigation volumes per tree were calculated from irrigation times, emitter flow rate (0.5 gph) and number of emitters per tree (8). Sodium chloride (86.2 mg/L) and sodium sulfate (209 mg/L) were continuously added to the irrigation water at a 1:1 molar ratio, resulting in an electrical conductivity (EC) of the irrigation water of 0.92 dS/m (measured using an EC meter). The drainage water for each tree was collected in plastic bags attached to the end of the drainage pipe. The volume was measured daily using a 2 L cylinder with graduation or a bucket with graduation if the volume was greater than 2 L. Since the capacity of the bags (13 L) was exceeded in some cases, additional measurements were taken (irregularly) where drainage was collected only over a few hours. If the capacity of the bag was exceeded and no additional measurements were available, the volume was assumed to be 20 L (which is in the range of short-term measurements taken for bags that were full after a day). An average drainage volume for each day and for each tree was calculated by dividing the volume collected by the time over which drainage was collected. All trees were fertigated with calcium nitrate once for 4 hours on 09/26/2019 (81 mg N per liter of irrigation water).

## Soil measurements

Soil moisture was measured using a neutron probe at three different locations and depths 15, 25, 35, 45, 60 and 75 cm. Midday stem water potential was measured for all trees (one leaf per tree) using a PMS instruments pressure chamber after covering the leaf with an aluminum foil bag for at least 10 minutes. Porewater samples were taken for 6 trees sampled (three trees in the T1 treatment and three trees in the T3 treatment). Sixteen Pore water samplers (Irrometer) were installed per tree in a grid pattern (depths 10, 25, 45 and 80 cm and at 0, 30, 60 and 90 cm distance from the midline of the tub). Samplers were installed at a 60-degree angle to avoid preferential flow. Tension was applied (ca. 80cbar) in the afternoon the day before samples were taken (2 days before for 09/25) with a vacuum pump. Samples taken were transferred to 15 ml falcon tubes and transferred to the laboratory in an ice-filled cooler and analyzed for EC. A subset of the samples was also analyzed for nitrate concentration.

## Results

There is very little temporal variation in volumetric soil water content and even the water content at 15 cm depth does not show a lot of short-term variation in response to irrigation and drying between the irrigation events (Fig. 18). Water content generally increases from top to the bottom of the lysimeter and as the water content changes with time throughout the measurement period, the changes seem to occur more or less simultaneously at all depths so that the lines remain parallel. Overall, water content decreases until 09/26/2019 and then slowly increases for most measuring locations. Midday stem water potential is close to the baseline during the entire period (Fig. 17) which was expected due to the low atmospheric demand. The deviation from the baseline is less than 2 bar except for Oct. 1. There is not much systematic difference between the treatments and no clear response to the irrigation times indicating that the plants were well watered the whole time regardless of the irrigation interval.

The nitrate pulse is clearly visible in the EC time series (Fig. 19). The peak is most intense at 30 cm and 60 cm distance from the middle line of the tub (the emitter is at about 30 cm distance). The response to the nitrate pulse has a similar shape across depths and occurs only slightly later with depth (about 0.5-1-day delay) but differs between tubs and with distance. There is little temporal variation at 90 cm distance and EC overall increases with depth and is especially high at 90 cm distance from the midline. Average root zone nitrate concentration increases at the beginning of the period (after the injection) and then decreases to almost the original value and there is little difference between treatments (Fig. 20). The number of obtained from the pore water samplers per treatment increases from about 30 to 40 until 09/28/2019, probably as a result of increasing soil moisture, and then remains constant. Of the samples analyzed, only very few had nitrate concentrations above the detection limit of 1 mg/L.

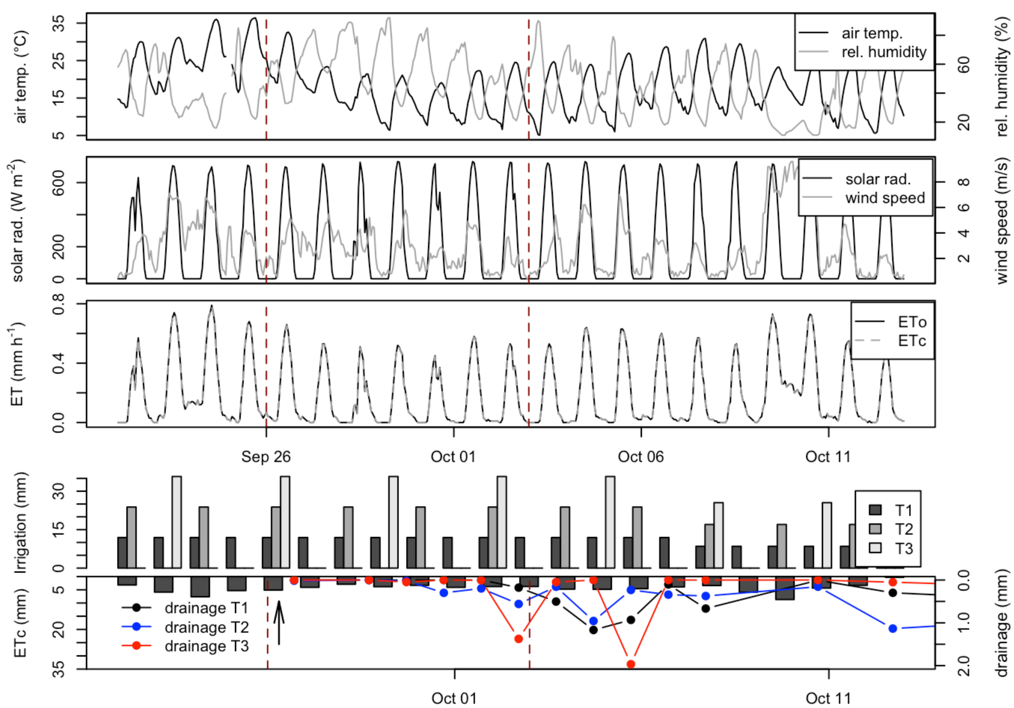



***Fig. 16:*** *Meteorological data and irrigation and drainage amounts for treatments T1 (daily irrigation), T2 (irrigation every 2 days) and T3 (irrigation every three days). The beginning and end of the measuring period are indicated by vertical dashed lines. The volume of the irrigation water was normalized by the area of the tub (which is approximately the area shaded by the tree; the total area of the field would be about seven times larger) in order to calculate irrigation in mm. One tree (tree 41) had to be removed from the drainage data for treatment 3 because of a malfunctioning drip emitter that caused a significant overapplication of water and was replaced on 09/26/2019. The sampling bags for drainage water have a maximum capacity of about 13 liters. Thus, if the drainage volume for a given tree exceeded the capacity of the bag, the drainage volume for that tree was arbitrarily assumed to be 20 liters. The arrow indicates the start of the 4-hour fertigation pulse (calcium nitrate) at the beginning of the measuring period.*

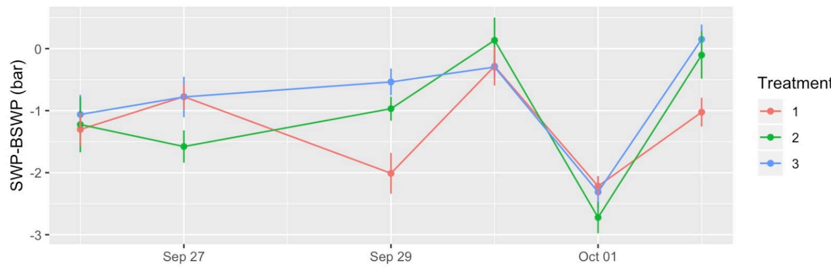



***Fig. 17:*** *Treatment averages of the difference of the stem water potential (SWP) from base line stem water potential for prune (BSWP). Error bars denote standard errors.*

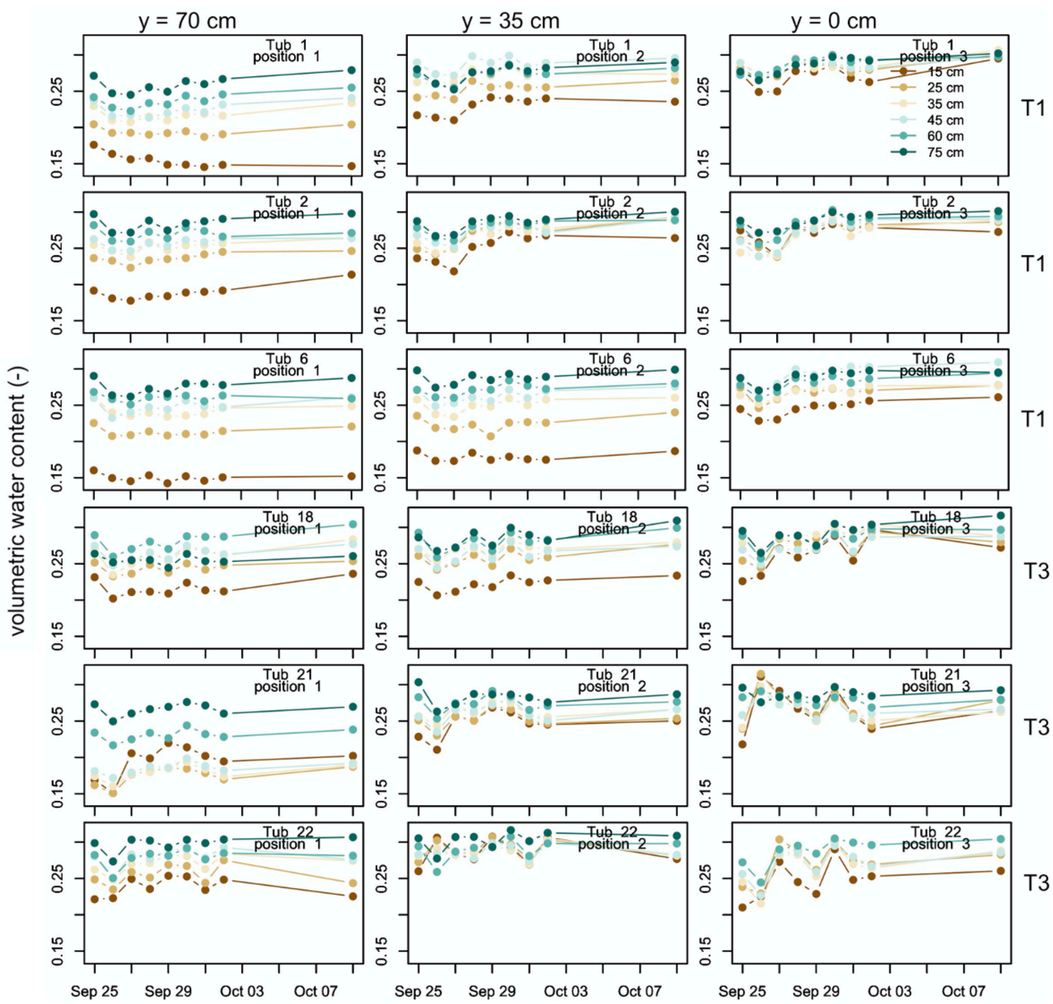



***Fig. 18:*** *Soil moisture measured using the neutron probe in three different access tubes per tree (at 0, 35 and 70 cm distance from the middle line of the lysimeter). Only data for the trees with Nemaguard rootstock are shown. T1: irrigated every day. T2: irrigated every two days. T3: irrigated every three days.*

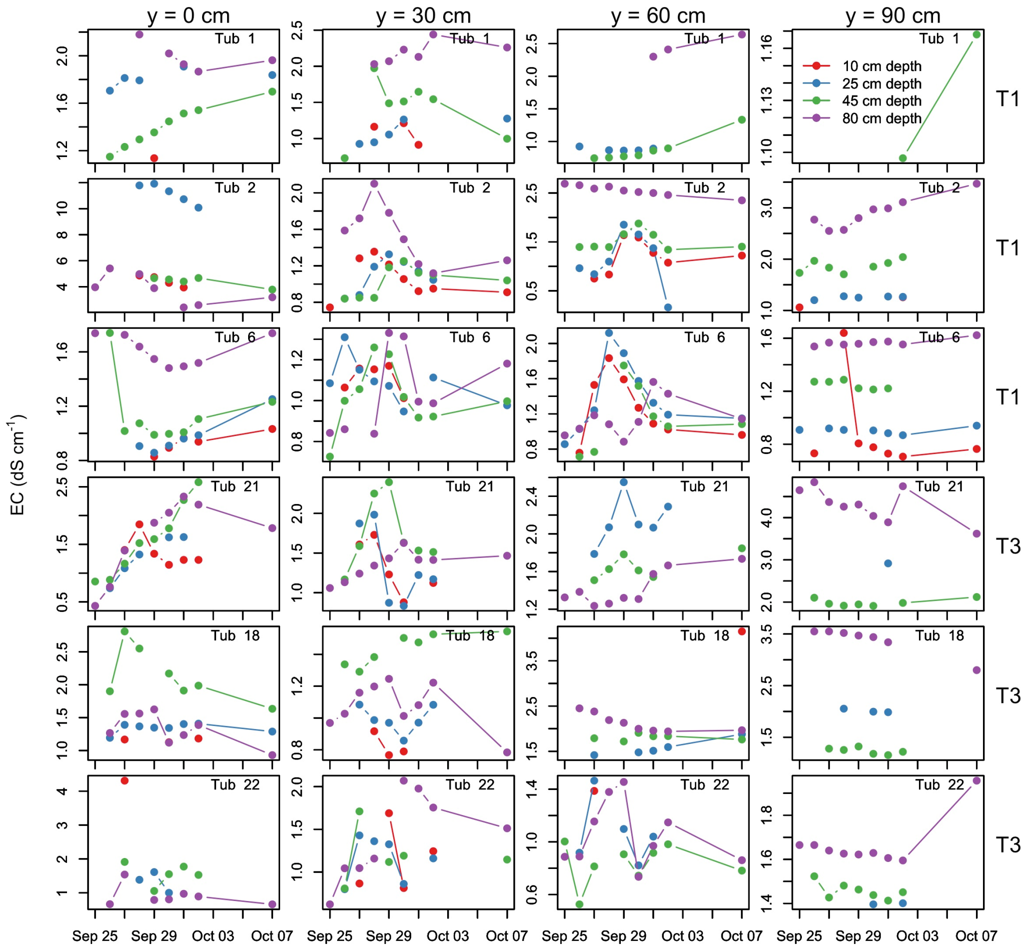



***Fig. 19:*** *Raw data of EC over time from treatments HFS (T1) and LFS (T3) from September/October 2019.*

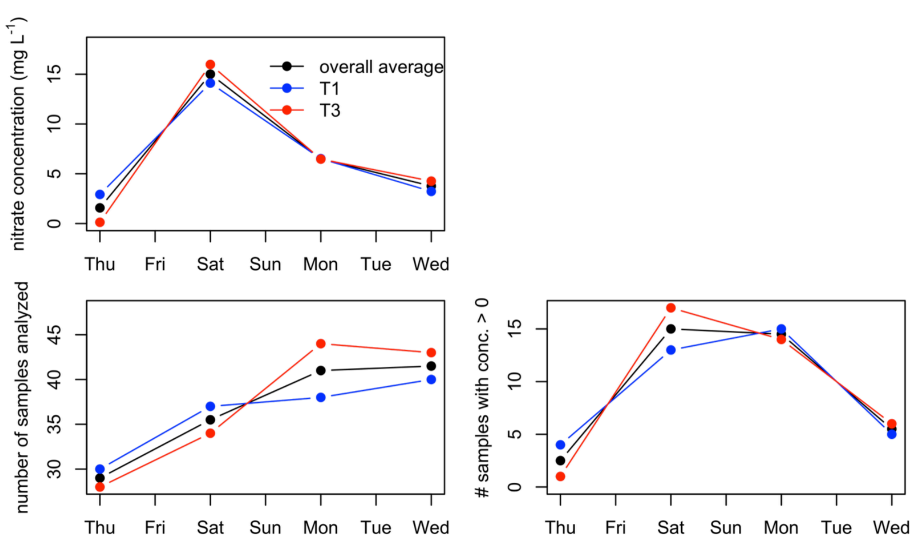



***Fig. 20:*** *Top. Treatment averages of the nitrate concentrations of the porewater (averages across all 16 sampling positions per tree and across all three trees per treatment) for 09/26/2019, 09/28/2019, 09/30/2019 and 10/02/2019. Bottom left. Number of samples the averages in the left graph are calculated from. Bottom right. Number of samples with concentrations above the detection limit.*

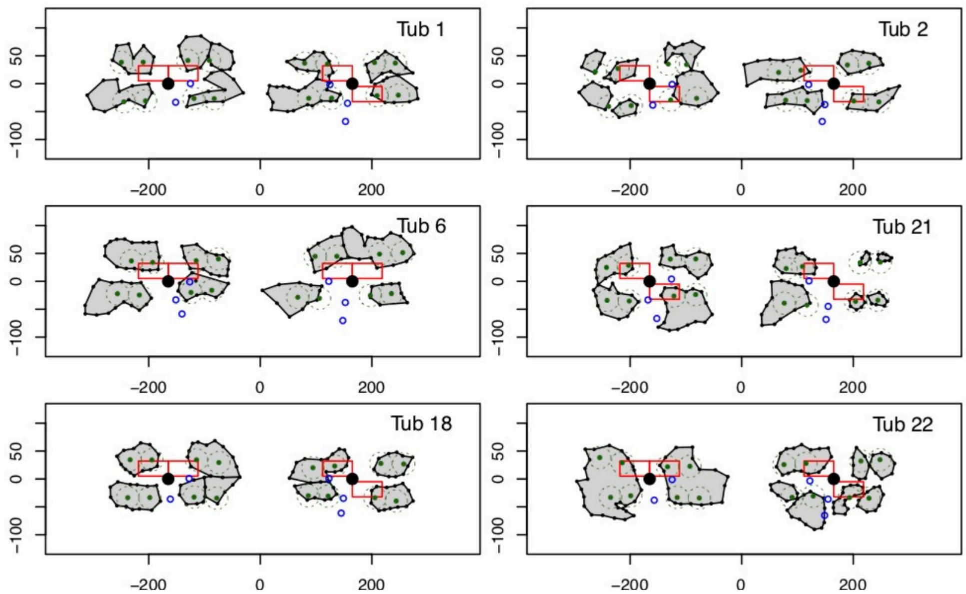



***Fig. 21:*** *Areas (grey) wetted by the drip emitters (green) digitized from photos. Blue circles indicate the positions of neutron probe access tubes. Nemaguard right, Viking left.*

## References:

California Department of Water Resources (2019): CIMIS. California Irrigation Management Information System. https://cimis.water.ca.gov

Fulton, A. (2018): Using Baseline SWP for Precise Interpretation. Sacramento Valley Orchard Source. University of California, Agricultural and Natural Resources. http://www.sacvalleyorchards.com/manuals/stem-water-potential/using-baseline-swp-for-precise-interpretation/

## M. 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:** 2020
**Location:** Davis, CA
**County:** Yolo County

### Highlights

- Experiments were conducted to evaluate the effect of low vs. high irrigation/fertigation frequency on the deposition pattern of salt within the root zone, and on plant growth.
- It was shown that a low-salinity zone below the drip-emitters with particularly high root abundance exists regardless of irrigation/fertigation frequency.
- The irrigation/fertigation frequency had a significant effect on leaf concentrations of Cu, Fe, Mg and Zn but not on leaf Cl or N concentrations or tree growth in 2020.
- The results are in agreement with the observation in previously conducted split-root-experiments that trees preferentially use parts of the rootzone with favorable conditions, but an effect of irrigation frequency on overall tree growth has not been observed yet.

### 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. The experimental design is a factorial design, including 3 levels of irrigation/fertigation treatment (HFS: daily irrigation and fertigation with saline water; HFNS: daily irrigation and fertigation with non-saline water; LFS: fertigation every 8 days and irrigation every 4 days with saline water), two different rootstock (Nemaguard and Viking), and two different soil types (sandy loam and loamy sand). There were four trees per treatment combination. Calcium nitrate was used as an N fertilizer and total amount of N and total amount of water applied were the same for all treatments. The root zone was instrumented with porewater samplers, neutron probe access tubes, and mini-rhizotrons to collect data on water, salts, nitrate and root growth. Moreover, trunk diameter was measured as a measure of tree growth, leaf samples were collected in August 2020, and soil samples were taken in October 2020 and analyzed for soil electrical conductivity (EC) and root abundance. 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.

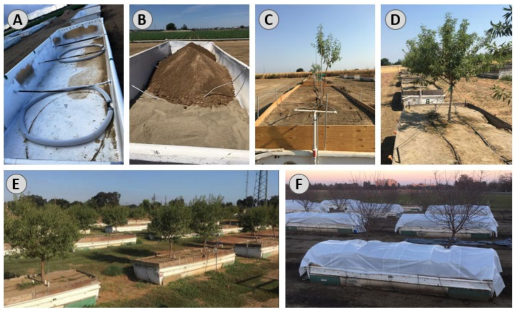
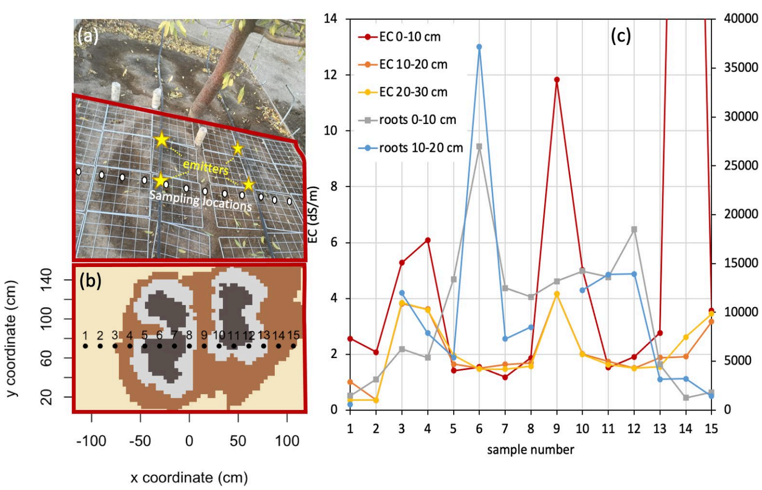



**Fig. 1:** Construction of the 24 drainage lysimeters. A- Drainage pipe covered with a screen and connected to an outlet in the wall of the tomato truck bin. B- Bin being filled with a layer of coarse sand at the bottom and loamy soil above. C- Young almond trees after transplanting into the bins. D-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

A low-salinity zone was observed under the area wetted by the drip emitter in both the HFS and LFS treatments (Fig. 2, data for HFS not shown). Higher salinities were observed in the middle between the driplines and at the edges of the wetted area, where soil salinity can reach values exceeding 10 dS/m. Root abundance is also clearly elevated within this zone compared to samples taken between the driplines or at the margins of the wetted zone. Leaf chloride concentrations are significantly higher in the saline treatments HFS and LFS than in the non-saline treatment HFNS (Fig. 3) but are not significantly affected by irrigation/fertigation frequency (no difference between HFS and LFS). However, the LFS treatment shows significantly lower leaf Zn and Cu concentrations, and by higher Fe and Mg concentrations compared to HFS. No effect of the irrigation/fertigation treatments on tree growth has been found so far.



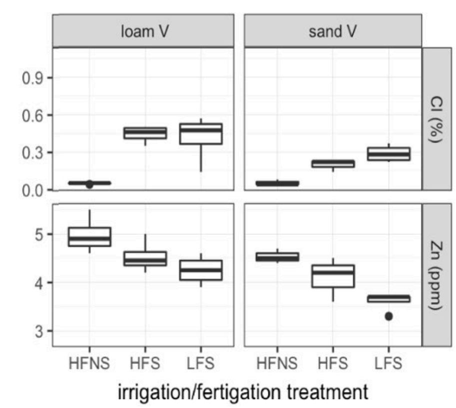
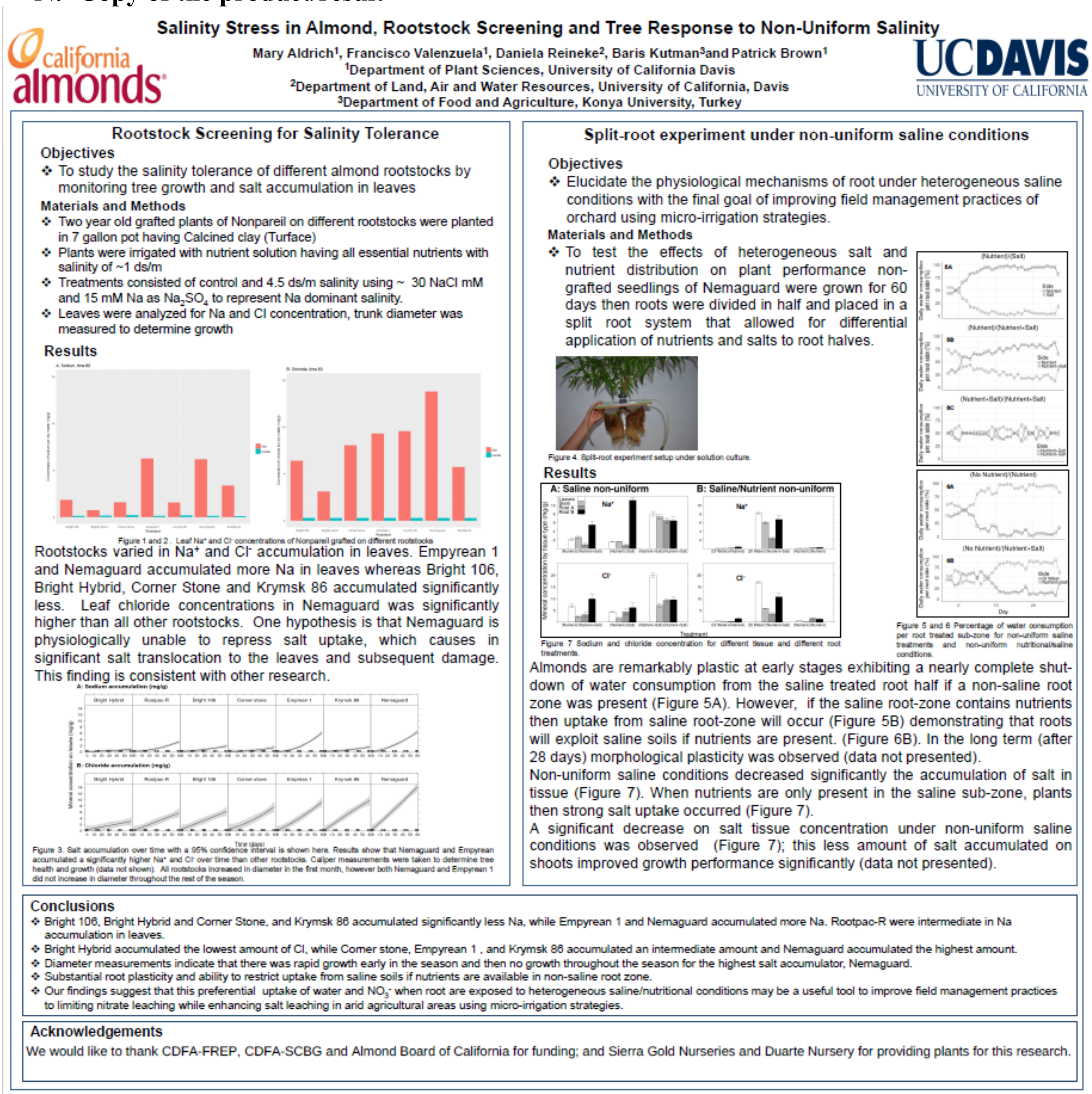




**Fig. 2:** Soil sampling results. (a) picture of the sampled surface area in tub 22 (LFS, Viking, sandy loam). (b) Sampled area as a soil color map illustrating the areas wetted by the drip emitters (areas that are flooded during irrigation in dark grey) and the location of the 15 soil samples. (c) Electrical conductivity (EC) of the saturated paste extract of the samples at three different depths and relative root abundance at 0-10 cm and 10-20 cm depth.

**Fig. 3:** Leaf Cl and Zn concentrations in August 2020 for the different irrigation/fertigation treatments (HFS: high frequency, HFNS: high frequency, low salinity, LFS: low frequency) and soil types (sandy loam and loamy sand). Data only shown for the Viking rootstock.

## N. Copy of the product/result



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

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

#### 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 $Na_2SO_4$ 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 $Na^+$ and $Cl^-$ concentrations of Nonpareil grafted on different rootstocks

Rootstocks varied in $Na^+$ and $Cl^-$ 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 $Na^+$ and $Cl^-$ 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 7 Sodium and chloride concentration for different tissue and different root treatments.

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

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).

#### 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 $NO_3^-$ 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.

#### 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. 22:*** *Poster presented at the Almond Conference in Sacramento in December 2017.*

# Salinity Screening for Almond and Tree Response to Non-Uniform Salinity


Saiful Muhammad[1], Mary Aldrich[1], Daniela Reineke[2], Baris Kutman[3], Francisco Valenzuela[1] and Patrick Brown[1]
[1]Department of Plant Sciences, University of California Davis
[2]Department of Land, Air and Water Resources, University of California, Davis
[3]Department of Food and Agriculture, Konya University, Turkey


## 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.

| | | Chloride concentration on leaves (%) | |
|---|---|---|---|
| Ranking | Rootstock | Field study[1] | Pot study[2] |
| 1 | Hansen*** | 0.15 | [illegible] |
| 2 | Bootjack* | 0.17 | [illegible] |
| 3 | Bright's5* | 0.18 | [illegible] |
| 4 | BB106* | 0.19 | [illegible] |
| 5 | Viking** | 0.20 | [illegible] |
| 6 | Empyrean1* | 0.33 | [illegible] |
| 7 | Nemaguard* | 0.57 | [illegible] |
| 8 | Krymsk86* | 0.89 | [illegible] |

**Table 1.** Contrast between field and pot trials. [1]Data from study performed by Duncan and Holtz (2017), [2]Data from different studies performed by Kutman, Muhammad, Aldrich, Valenzuela and Brown between 2015-2018. *Treatment: 4.5 dS/m salinity using ~ 2 NaCl and 1 $Na_2SO_4$ to represent Na dominant salinity. Leaf sampling measurements were performed after 60 days of applied treatment. **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. ***Treatment: 40 mM NaCl (EC = ~4.8 dS/m). Leaf sampling measurements were performed after 40 days of applied treatment.

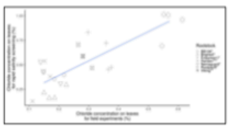


**Figure 1.** Correlation between field and pot studies.


**Figure 2.** Nonpareil almond trees grafted on different rootstocks (Nemaguard, 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 $Cl^-$ 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)

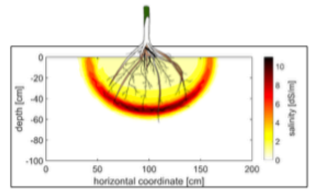



**Figure 4.** Simulation of field irrigation by using HYDRUS software. Nine irrigation events with a duration of nine hours each and irrigation water with EC=1 dS/m.

### 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

**Figure 5.** Picture of the lysimeter experiment established in Plant Environmental Sciences fields.

### 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.

### 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 $NO_3^-$ 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. 23:** Poster presented at the Almond Board Conference in December 2018 in Sacramento.*

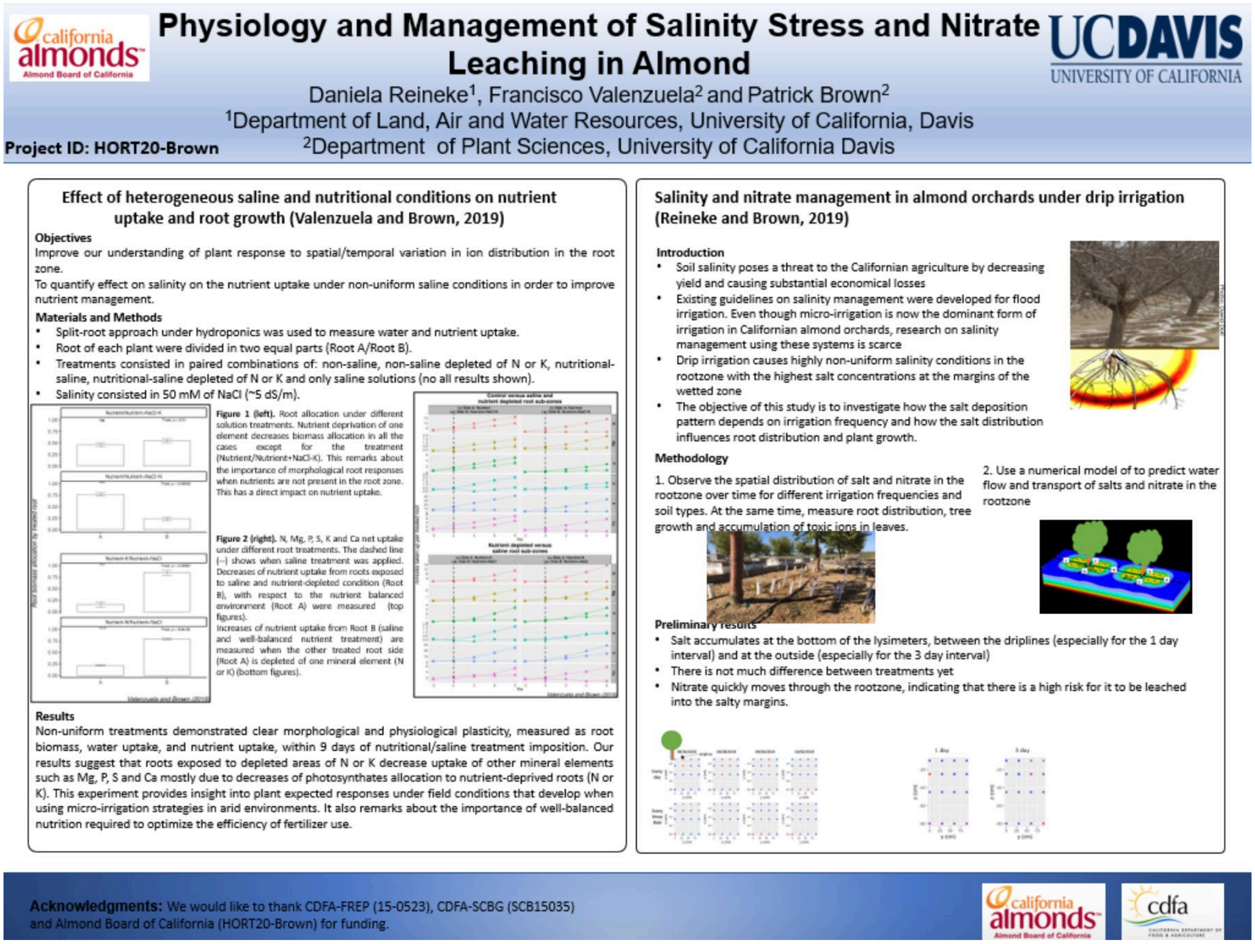



***Fig. 24:*** *Poster presented at the Almond conference 2019 in Sacramento.*

# Web Apps



## Development of Tools to Manage Nitrogen Fertigation

**Description:**

Microirrigation systems cause a spatially rather heterogeneous distribution of water in the root zone and the timing of irrigation and fertilizer injection has implications for where in the soil nutrient concentrations will be high. This tool was developed to demonstrate the effect of irrigation and fertilizer injection timing on the distribution patterns of nitrate and soil moisture in the root zone. The tool shows results of simulating a single irrigation event on a moderately dry soil. Simulations do not account for water or nutrient uptake of roots and evaporation from the soil surface and were done using the software HYDRUS 2D/3D (Šimunek et al., 2012), which numerically simulates the movement of water and solutes under unsaturated conditions in soils. The work was funded by the Specialty Crop Block Grant Program (SCBGP) and the Fertilizer Research and Education Program (FREP) of the California Department of Food and Agriculture (CDFA).

**Instructions:**

1. Select the **variable** to be displayed:

- Soil moisture change: Change in soil moisture relative to the initial soil water content
- Matric potential
- Nitrate concentration: Nitrate concentration of the pore water
- Nitrogen concentration: Nitrogen concentration of the pore water
- Nitrate content: Mass of nitrate per volume of soil

2. Select the **irrigation system**. For Fan-Jet (microsprinkler), a larger wetted area is assumed than for drip whereas the volume of water applied is the same.

3. Select the **irrigation duration** (between 3 and 24 hours).

4. Select the **flow rate**.

5. Select whether fertilizer should be injected **continuously** throughout the irrigation event or as a **pulse**. When selecting pulse, fertilizer injection can be started at different times after the start of the irrigation event (**6. Fert. Start Time**). Pulse duration (**7. Fertigation Duration**) can be either one or three hours. Only those timing options are available that allow the injection to stop at least one hour prior to the end of the irrigation event.

8. Select the **amount of N** to be applied.

9. Select the **soil type** by either selecting a soil texture or a soil series (soil series may have several horizons with different textures). Texture information of the soil series was obtained from SoilWeb (California Soil Resource Lab).

10. Select either centimeters or inches as length **unit** for the plot.

11. Click the **submit** button to generate the graph.

**Axis options:**

- Optimal for current settings: Cutoff values of the legend are selected based on the current graph to optimally show the spatial distributions.
- Fixed for current soil and irrigation system (works for soil moisture and matric potential, only): Legend remains the same when changing timing parameters.
- Custom: Enter custom cutoff values into the boxes next to the legend and click apply.
- Isolines can be added to the plot by specifying the desired values at which lines should be drawn in the box, separated by a comma (e.g. "0.03, 0.05, 0.1").

**References:**


California Soil Resource Lab. "SoilWeb." SoilWeb: An Online Soil Survey Browser. California Soil Resource Lab, casoilresource.lawr.ucdavis.edu/gmap/.

Šimunek, J., Van Genuchten, M. T., & Šejna, M. (2012). HYDRUS: Model use, calibration, and validation. Transactions of the ASABE, 55(4), 1263-1274.

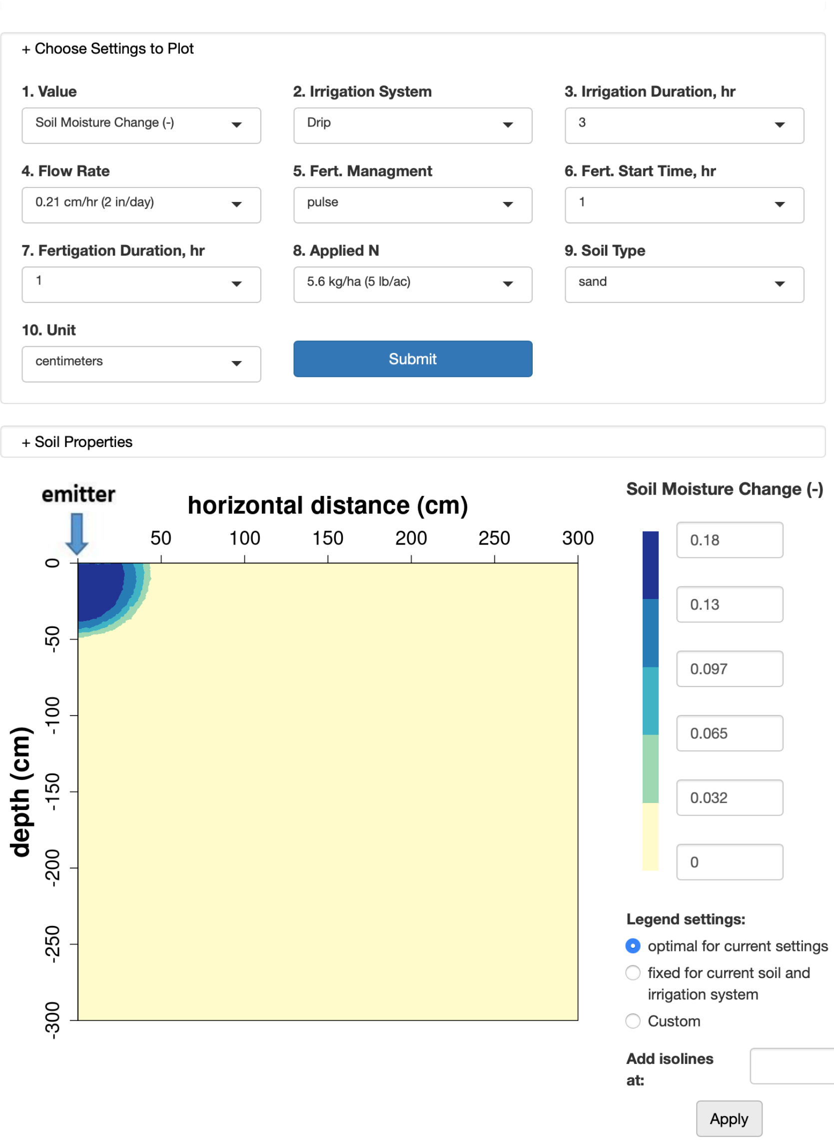




***Fig. 25:*** *Screenshot of the Nitrate/Irrigation Management Web application. URL: https://phbrown.ucdavis.edu/development-tools-manage-nitrogen-fertigation.*