A. Cover Page:

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

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   - SureHarvest, Soquel, CA.
   - The Burchell Nursery Inc., Oakdale, CA.

5. CDFA Funding Request Amount/Other Funding:

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B. Executive Summary

1. Problem

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.


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 consequence effect on N uptake by different rootstocks (salt-tolerant vs. salt-sensitive) of almond. This proposed research will be 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. We will collect data from different treatments for five years and will measure and evaluate a variety of soil/plant factors and parameters. Specifically, we will quantify 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 also 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.

3. Audience.

The primary target audiences are almond growers and crop consultants. However, the results of this experiment will be of value for citrus, pistachio, walnut and possibly row crops that utilize MI and are challenged by salinity. Other potential audiences include fertilizer industry, irrigation industry, state agencies (CDFA, ARB and CEC), farm advisors, CCA/PCA and non-governmental environmental agencies (Sustainable Conservation).

C. Justification

1. Problem.
Nitrate leaching from agricultural lands in California is a major source of groundwater contamination and a serious threat to the environment and public health. The use of nitrogen on agricultural lands has been identified as the major source of groundwater nitrogen contamination (Harter et al. 2012) and as much as 88 kg N/ha/year may leach to groundwater in areas where fertilizers are applied (Lockhart et al., 2013). This issue has been suggested to be resolved by developing irrigation practices that minimize the leaching of water and as a result nitrate.

Under Californian growth and soil conditions the majority of fertilizer N is rapidly nitrified, and the high mobility of nitrate makes it susceptible to leaching with the downward movement of irrigation water. The highest risk of nitrate leaching is associated with the first few irrigation events following a fertigation event, mainly due to high concentration of nitrate which exceeds plant capacity for uptake and the high mobility of nitrate in the root zone.

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. The challenges of managing nitrate leaching are greatly complicated when saline water is used. Almond is among the most salt sensitive species, the perennial nature of almond means damage is cumulative with time. An estimated 10% of almond acreage is salt impacted and an additional 30% is at immediate risk. Yields in 2014 were 280 million lbs ($1billion) below estimates due in large part to water and salinity stress. The current economic impact of salinity in almonds is estimated at $100-400 million (R Curtis, B Sanden, R Howitt pers comm). The use of irrigation waters containing

Fig. 1: A schematic of parameters affecting NO₃ leaching
significant salt require an increased leaching fraction and hence increases the risk of nitrate leaching.

Soil salinization in irrigated agriculture is typically mitigated through the growth of tolerant rootstocks and cultivars and remediated through the application of a volume of water sufficient to move the accumulated salts to below the effective root zone. While general strategies for management of salinity stress were developed in California when flood irrigation was the predominant irrigation strategy, there has been no study to our knowledge that provides guidelines for management of salinity in almond under micro-irrigation. With the new requirement that nitrate leaching be minimized in Californian agriculture, any salinity management strategy must also minimize nitrate leaching.

Under micro-irrigation, water is applied to a small volume of the total soil in the field resulting in greater proportional salt deposition in the active rooting zone. In contrast to flood systems in which salts are leached to below the root zone, salt deposition under micro-irrigation is toward the edge of wetting pattern in both lateral and vertical directions thereby keeping a considerable portion of salts within the 0-18 inch root zone. Over time, salinization at the margins of the irrigated zone will increase with a resultant decrease in the volume of soil in which tree roots can effectively function. Salts present at the margins of the wetted zone can subsequently move back into the active root zone with the occurrence of a rainfall, and this represents a substantial threat to a sensitive species such as almond. Root distributions under micro-irrigation are also far more restricted than under flood irrigation and hence plant response to salinity in the wetted zone under micro-irrigation is determined 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 reduced rooting zone and highly non-uniform salt deposition in the active rooting zone 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. The impact of salinity and the ability of roots to acquire nitrate will be proportional to the 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, were 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.

Proper irrigation/fertigation management guidelines for grower require a more detailed understanding of patterns of root growth and N uptake in response to non-uniform water and salt distribution; therefore, experimentation is required to determine the impact of salt accumulation in the root zone on nitrogen uptake. The application of irrigation water and fertigated nutrients, as well
as root distribution, and nutrient and water uptake all clearly interact with soil properties and fertilizer source in a complex manner that cannot easily be resolved with ‘experience’ or experimentation alone. Therefore, we will employ an existing and widely used modeling platform, HYDRUS, as an integrated water and nitrate management tool to conduct numerical simulation for different scenarios for a variety of almond cultivar, soil types, and different level of salinity. This will provide a means to transfer outcome of the treatments and findings of this project to other orchards with other soil types, tree root systems, almond cultivars etc. While this proposal is targeting almond trees, the concept and methodologies are valid for any crop and the modeling components of this proposal will facilitate the adoption of irrigation/fertigation management to different soil type, water quality and ET demand.

2. FREP Mission and Research Priorities.

The proposed research directly addresses most of the research priorities in CDFA/FREP 2015. This contributes to “advanced irrigation management to improve nutrient use efficiency”, “develop Best Management Practices (BMPs)” to optimize “strategies for timing of fertilizer application” to “minimize nitrate movement below the root zone”. Our calibrated and validated model will be used as an irrigation/fertigation management tool to develop guidelines for optimum water and nitrate management for any given almond orchard, thus “developing an integrated water and nutrient management tool”.

Lysimeter and field scale experiments will provide an excellent opportunity to demonstrate the comparative effects of salinity and irrigation management on growth, water and nitrate use efficiency under different (irrigation frequency, rootstock, and soil type) conditions. The lysimeters will allow for direct observation of changes in root growth, patterns of salinity accumulation and patterns of nitrate loss and hence will be an excellent educational facility for growers, consultants and agencies. The field sites will provide additional excellent demonstration opportunities and ideal locations for grower field days. The strong support for this proposal by commodity boards, nurseries and SureHarvest ensures that results of this research will be well disseminated and adopted. SureHarvest provides a powerful web based almond management system that is available free to all almond growers and is funded in the long term by the Almond Board of California, the results of this current project will be fully integrated into the Almond Board Sustainability website and toolkit.

3. Impact.

Almonds are a >$4 billion industry and California’s most valuable export crop. The beneficiaries include 6,000 almond growers, tree nurseries, more than 2,000 CCA’s/PCA’s, and industry employees, support and service industries involved in fertilization, irrigation, crop protection, harvesting, trucking, processing, packaging, food industry and consumers.

The required parameters for modeling tree response generated by the proposed research study will be incorporated into HYDRUS to perform simulation scenarios for different crop species, cultivar and rootstock and for the associated soil profiles (SoilWeb) where orchards are located. These results will immediately be useful to growers in choosing cultivars and rootstocks and to commercial and UC nurseries and breeding programs. The importance of this work for commercial nurseries is highlighted in the attached letter of support from Burchell Nurseries. Simulations will provide guidelines for existing practices and also recommendations for selection of cultivar and rootstock, irrigation system type
(single or double line drip, micro-jet) and scheduling to achieve the dual target of optimized salt leaching with minimized loss of nitrate. This project will provide easily accessible nitrate-sensitive salinity management guidelines for all growers of nut crops and a modeling platform to design nitrate-sensitive salinity management plans for any given specific condition for the advanced growers and farm advisors.

4. Long-Term Solutions.

The proposed approach would provide improved fertigation/irrigation management for micro-irrigated almond under saline conditions. The key component of the proposed approach is to develop micro-irrigation and fertigation strategies to increase N use efficiency under saline conditions, minimizing the downward movement of nitrate below the root zone while maximizing nitrate uptake and leaching of salts. This will be accomplished through a better understanding of the movement of saline and nitrate salts under micro-irrigation and by improving our understanding of the impact of salinity and non-uniform salt distributions on nitrate uptake and plant growth by diverse almond rootstocks.

5. Related Research.

Nitrate contamination of groundwater across the Central Valley is well documented and has been related to diverse and intensive agricultural production in the valley (Lockhart et al., 2013). Many researchers have attempted to quantify the water and nitrate fluxes below the root zone of agricultural crops using a variety of methods including mass balance approach and nitrate concentrations with depth in the soil profile (Asadi et al., 2002; Constantin et al., 2011; Paulino-Paulino et al., 2008; Thomsen and Hansen, 2014), using isotope analysis (Yang et al., 2014), and lysimeters (Arauzo et al., 2010; Fonder et al., 2010; Skaggs et al., 2012). However, none of these methods has become a wide-spread practice in agriculture, due to limited scale that they operate on, the difficulties in measuring their many input parameters, their associated uncertainties among other reasons. Kandelous et al (2013) and Moradi et al. (2014) have recently developed the necessary instrumentation to calculate downward fluxes of water and nitrate at the scale of single tree, plot, and an orchard. By calculating the gradients in water potential across a soil layer deep below the root zone with known soil hydraulic properties, the daily fluxes of water and nitrate (measured concentrations) can be calculated using Darcy equation. This is a major step in moving forward with quantifying contributions of certain cropland and/or a certain agricultural practices in releasing nitrate below the root zone of crops. This method has been implemented in various projects including tomato (Burger and Hopmans), citrus (Kandelous and Hopmans), almond (Hopmans, Brown and Kandelous), pistachio (Hopmans and Brown), and walnut (Pope, Brown, and Hopmans).

Plant growth for an essential nutrient can be described as a curve with a sub-optimal, optimal and supra-optimal nutrient concentration in which the nutritional deficiency and toxicity can be observed under sub and supra nutrient concentrations affecting negatively plant growth. Saline conditions can change optimal range of the curve widening, narrowing or moving the range right or left depending of crop, cultivar, particular nutrient, type and level of salts, or environmental condition (Grattan and Grieve, 1998). This change of behavior in the element uptake can be explained as imbalances for competition of Na+ and Cl- with nutrient such K+, Ca+2 and NO3- (Hu and Schmidhalter, 2005). Recently it was demonstrated that chlorine is the anion which causes toxic accumulation in almond (Kutman, unpublish data). Studies in grapes and citrus suggest a) an antagonism between Cl- and NO3-. Increases in the amount of applied
nitrate have decreased the Cl- accumulation in leaves for avocado and citrus (Bar et al., 1997), but increase the risk of nitrate leaching.

The high level of complexity in interaction between micro irrigation systems, irrigation scheduling, fertigation management, root distribution and uptake rate of water and nutrient, and soil properties can only be resolved through the use of a modeling approach means that can identify the optimum irrigation/fertigation management for specific conditions. Given advances in computer science and knowledge of soil water movement and solute transport, researchers have increasingly used mathematical models in order to simulate water movement (Andreu et al., 1997, Kandelous and Simunek 2010 a&b, Kandelous et. al. 2011), nutrient (nitrate) transport (Gardenas, et al. 2005, Hanson, et al. 2006 a&b), salinity and salt leaching (Hanson et al. 2008; Hanson et al. 2009), root water and nutrient uptake (Šimůnek and Hopmans, 2009), and also use the modeling platform to find the optimum irrigation design and scheduling (Kandelous, et. al., 2012, Dabach, et. al., 2013).

6. Contribution to Knowledge Base.
    Almonds are considered salt-sensitive with a general osmotic threshold of 1.5 dS/m. This value however was developed without consideration of rootstock or cultivar and without considering advances in irrigation systems. There is limited information on the effect of salinity on N uptake and root plasticity on N uptake from root zones with non-uniform salinity level in almond. To the best of our knowledge, this proposed research would be the first to comprehensively evaluate the effect of uniform and non-uniform salinity distribution in the root zone on N uptake and salinity responses of different almond rootstocks and soil type. We expect to improve our understanding of how irrigation/fertigation strategies can contribute to reducing nitrate leaching while maintaining the productivity under saline conditions. We will also contribute to the existing management tools by developing an integrated water and nutrient management tool in order to provide optimum irrigation/fertigation management for any given condition.

7. Grower Use.
    As growers utilize increasing amounts of salinity compromised ground and surface water and as they are being mandated to reduce nitrogen loss to the environment, they are increasingly being expected to develop improved irrigation/fertigation management simultaneously allow for salt leaching while maximizing nitrogen use efficiency. It is a difficult challenge for which our existing knowledge and available management strategies are very limited. The development of guidelines that growers can use in making irrigation decisions that simultaneously limit nitrate loss while optimizing leaching, is desperately needed.

D. Objectives
    The objective of this project is 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 different rootstocks (salt-tolerant vs. salt-sensitive) of almond. This proposed research will be conducted in lysimeter tanks and at a field scale. The large lysimeters will allow trees to grow to full commercial size while also allowing for precise monitoring of applied water and salinity, precise measurement of environmental conditions and easy access to the soil volume for detailed
sampling and analysis that cannot be easily achieved under field conditions. By conducting these experiments in both controlled but large-scale trials at UCD and validating them in commercial orchards we provide the best opportunity for integrity and usefulness of results.

The collected data will also be used to validate and calibrate an existing modeling platform, HYDRUS. This model will be used as an integrated water and nitrate management tool to develop alternative irrigation/fertigation methods for different variety 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.

Comments on TASC Recommendations and changes to scope of original concept proposal:
TASC made 3 recommendations:

1) Conduct all or most research in commercial orchards
2) Utilize HYDRUS 2D
3) Include validation of model in the field

As advised we will adopt HYDRUS 2D modeling. However to do this will require detailed information on biological parameters of rootstocks such as nutrient uptake rates, root plasticity, root salinity response and water uptake that is needed to populate the HYDRUS 2D model. We are in a unique position to acquire these parameters by utilizing an ongoing Almond Board funded greenhouse trial currently underway in the PI’s laboratory. Unfortunately, the Walnut Board did not fund an equivalent study in walnut and hence we will not have access to the required biological parameters needed for HYDRUS 2D modeling in walnut, and we cannot feasibly gather this data given funding limits of FREP. As the letter of support from the Almond Board clearly demonstrates, the funding of this project by FREP would be a tremendously valuable contribution to the Almond industry and a highly synergistic activity.

While we appreciate the benefit of commercial orchard based research we feel that the costs and challenges of conducting the primary HYDRUS 2D model development and initial validation in commercial fields is prohibitive and that the vagaries of commercial production, and lack of uniformity and unknown state of sub soils in an established orchard, would greatly complicate this experiment. On-farm experimentation faces a substantial risk of inadvertent grower disruption (unscheduled or altered irrigation practice, changed water source, altered fertility management, miscommunications etc) that could compromise the project. By using large lysimeters we allow unimpeded tree growth, absolute control of irrigation and fertilization and salinity, real time measurement of all environmental parameters and complete access to the entire soil profile for installation of soil probes and direct soil and soil water sampling. The integrity of models developed under these conditions will be far greater than could be achieved in commercial orchard trials.

While we will not conduct the bulk of this research in commercial orchards we will intensively validate and demonstrate the project outcomes in years 4 and 5 in commercial orchards. This activity will be guided by findings from the lysimeter experiments. Therefore, we propose a 5-year project where we establish and instrument our lysimeters and selected field trials in year 1, devote years 2 and 3 for extensive monitoring of the lysimeter experiments and periodic measurement of selected field trials for model calibration and validation. The model-suggested optimum management for each treatments will be applied to our lysimeters and simultaneously to selected field sites. The lysimeter trial will serve as an excellent outdoor
laboratory for field days, demonstrations and outreach events. Commercial validations sites will be used for field days to highlight work conducted at Davis and validity for field implementation. We believe this is the most effective approach to achieve the goals of this project.

Objectives:
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.

E. Work Plans and Methods

Task 1. Experimental design and instrumentation (Years 1, 2, and 3):

a) Experimental design

Lysimeter:
We will establish almond trees at the UCD Plant Sciences field research facility in large tomato truck bins measuring 28 x 8 x 5 ft (L×W×D) which are large enough to plant 2 trees at a spacing of 14 foot between trees. Eight treatments x 3 replicates for a total of 24 tomato truck bins will be used. Bins will be filled homogenously with two (course and fine texture) typical of soil compositions found in almond growing regions of California. These tubs are large enough to allow for unencumbered root growth for several years while simultaneously allowing for easy installation of instrumentation, easy access to soil for analysis through soil surface and bin sides, easy collection of leachate, easy monitoring of tree growth utilizing digital imagery. The proximity to UCD offers the opportunity for intensive monitoring and sub-sampling that is much more expensive, difficult to obtain and frequently confounded in trials conducted on grower fields.

Treatments are designed to determine tree response to eight treatments consisting of two irrigation management (high vs. low frequency), two soil types (course vs. fine texture), and two different rootstocks (salt-tolerant vs. salt-sensitive) of almond. N fertilizer will be applied following the commonly practiced fertigation regimes in which nutrients are applied in the irrigation water in 4 fertigation events (April, May, June, October). The frequency of irrigation and the amount of applied water in each irrigation treatment will be calculated based on soil water holding capacity, evapotranspiration, and the leaching requirement. Plants in all treatments will be irrigated with moderately saline (EC 1.5dS) irrigation water so that a measurable accumulation of soil salts will be observed in periphery of wetting zone, but not so high that plant growth will be profoundly affected. We have a current stock of two year old trees growing in large pots that will be used for this trial.

Field:
Field trials corresponding to the best irrigation approaches identified from lysimeter studies will be selected for baseline monitoring of plant and soil water/nutrient status under grower irrigation/fertigation management (year 2 and 3) and model-suggested optimum irrigation/fertigation management (year 4 and 5).

b) Instrumentation plan and data collection methods (Year 1, 2, 3):

In all treatments we will monitor the patterns of nitrate uptake/depletion, water use and salinity utilizing a variety of installed probes as shown in Fig. 1. All the instruments will be installed during filling the lysimeters to ensure ideal soil contact. One replicate from each treatment will be extensively instrumented using 5TE soil moisture sensors, solution samplers, tensiometers, and neutron probe access tubes for both continuous (24/7) and alternating days monitoring of soil water, salinity, and nitrate status as well as leaching, while the other two replicates and selected field trials will be instrumented with tensiometers, solution samplers, and neutron probe access tubes for alternating days (bi-weekly for field scale) monitoring.

Leaching of water and nitrate will also be monitored by collecting drainage water from all lysimeters. All 5TE sensor and tensiometer readings will be recorded hourly on dataloggers. The 5TE sensor, neutron probe, and solution samplers monitor the soil water content, soil temperature, soil salinity, and soil nitrate concentration within the root zone in a three-dimensional fashion (multiple sensors at multiple depths and distances from the trunk). The tensiometers will monitor soil matric potentials below the root zone and will be used to calculate the downward fluxes of soil solution. In all treatments we will monitor tree water status using the pressure bomb and will periodically utilize digital image analysis to monitor tree growth and take tissue and soil samples to monitor salt and nitrogen concentrations.

c) Soil hydraulic properties (Year 1):

The soil hydraulic properties will be determined in the laboratory.

![Fig. 1. The instrumentation layout of lysimeters.](image)

Table 1: The total number of lysimeters and associated instrumentation. Eight treatments each
replicated 3 times with two almond trees in each lysimeter.

<table>
<thead>
<tr>
<th>Irrigation frequency</th>
<th>Soil type</th>
<th>Rootstock</th>
<th>Instrumentation</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Heavily instrumented lysimeter</td>
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<td></td>
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<td>Soil moisture sensor (STE), neutron probe, tensiometer, solution sampler</td>
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<tr>
<td>Low</td>
<td>Sandy</td>
<td>Nemaguard</td>
<td>1</td>
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<td>Viking</td>
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<td>Loamy</td>
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<td>Nemaguard</td>
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<td>Viking</td>
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<td>High</td>
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<td>Viking</td>
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**Task 2:**

a) *Tree Growth and Development and Nutrient Analysis (Years 1, 2, 3, 4, and 5):*

Trees will be photographed periodically and the images will be analyzed by ImageJ to estimate the canopy size and monitor the growth. Additional growth data will be obtained from trunk diameter measurements. Mature leaf samples will be collected periodically for mineral analysis. Whole-plant evapotranspiration, stem water potential and microcalorimetry measurements and carbon isotope discrimination analysis will be used to evaluate salinity-induced water stress.

b) *Quantifying leaching and N Use efficiency (Years 2, 3, 4, and 5):*

Tensiometers will be used to monitor soil matric potentials below the root zone and will be used to calculate the downward fluxes of water. The calculated water flux combined with the nitrate concentration of soil solution from deepest solution sampler will be used to determine nitrate leaching. We have established a method for calculating these fluxes in our previous studies (Kandelous et al., 2013; Moradi A. B. et al., 2014).

In lysimeter scale experiment, leaching of water and nitrate will also be monitored using the drain system implemented for all lysimeters as a reference to cross-validate our in-situ methodology for estimating downward flux of water and nitrate at field scale. The applied N fertilizer, and data collected for analyzing the soil and plant N status as well as the amount of N in leaching water will be used to quantify N use efficiency for each treatments.

**Task 3. Modeling Scenario analysis (Years 2, 3, 4, and 5):**

a) *HYDRUS calibration (year 1 and 2)*

For HYDRUS to produce realistic outputs, almond-specific biological parameters related to water, salt and nitrate uptake and root plasticity under salinity stress must be determined and used as input parameters in addition to soil physical properties, irrigation, ET
and fertigation parameters. The required biological parameters including N uptake parameters and root plasticity will be derived through extensive greenhouse experiments funded by Almond Board of California.

**Uptake parameters:** The extensive dataset obtained from on-going experiment (funded by ABC) will be used to determine NO₃⁻ uptake parameters (Vₘₐₓ and Kₘ) using the inverse modeling technique.

**Root plasticity:** The proportional water and nutrient uptake pattern measured in split-root experiments (funded by ABC) will be used to determine the effects of root plasticity on water and nitrate uptake under non-uniform saline condition. Similar to the procedure described above, the inverse modeling approach will be used to obtain root plasticity parameter in water (ωₗ) and mineral (πₗ) uptake under non-uniform salinity stress.

b) **HYDRUS simulation (year 2 and 3)**

The timing and amounts of applied water and nutrients, the quality of the irrigation water and ET values will be applied to the HYDRUS model as input parameters and the simulated soil water content, salinity, matric potential, root water uptake, nitrate uptake, and leaching will be cross-validated (and if needed fine-tuned) with the observations from both lysimeter and field scale experiments. After calibration and validation of the model, HYDRUS will be used to develop the optimum irrigation/fertigation managements for given almond variety, soil profile (texture and layering), irrigation system (drip and fanjet), and fertilizer source from lysimeter and field scale experiments.

c) **Evaluation and guideline development (year 4 and 5)**

In order to evaluate the simulation results of HYDRUS, the optimum irrigation/fertigation managements will be applied to lysimeter and field experiments. We will monitoring soil and plant water, salinity and N status. The HYDRUS-2D model will then be used as an integrated water and nitrate management tool to conduct numerical simulation for different scenarios for a variety of almond cultivar, rooting systems, soil types, and different level of salinity. This will provide a means to transfer outcomes from this project into other orchards with other soil types, tree root systems, almond cultivars etc. This way we can provide valuable information and construct general guidelines for the growers across the state and the nation.

**Task 4. Outreach program (Years 2, 3, 4, and 5):**

Field demonstrations at the UCD experimental will be held in years 2, 4 and 5. We will present our findings at the fall FREP Conference, annual almond conference, farm advisor almond days, ASA meetings and other venues. Third, we will participate in outreach events, workshops, and symposia sponsored by University of California and its extension units, and Almond Board of California conference, among others. Fourth, we will make available short summaries of our work to be published in the form of newsletters, technical articles and others in various outlets including the ABC newsletter. Fifth, we will write extension articles for the Agriculture and Natural Resources (ANR) Extension Bulletins and trade news outlets. Sixth, at the end of the project we will submit at least one article for publication in a scientific journal. This project has strong industry support and through the
ABC will be widely publicized and presented. The project will develop online toolkits that will be made available for free grower distribution (FNRIC and Almond Sustainability Website) – see letters of support for documentation.

F. Project Management, Evaluation, and Outreach

1. Management.

Patrick Brown and Maziar Kandelous will design all experiments, supervise staff and data collection, conduct statistics and prepare all reports and subsequent publications. Maziar Kandelous has been working on various aspects of optimizing irrigation management in almond and citrus orchards and Patrick Brown is leading several projects with various commodity boards (almond, walnut, pistachio). We will meet regularly and coordinate the proposed work from instrumentation to data interpretation and developing guidelines. Jirka Simunek is the developer of HYDRUS model and will assist in modeling and any required modification. Steve Grattan will assist in designing salinity treatments and interpretation of salinity induced-stressed outcomes. Blake Sanden will assist in field designing and managing field experiments and facilitate grower workshops and outreach programs.

2. Evaluation.

The pros and cons of the nitrate-sensitive irrigation/fertigation management in comparison with the standard practice will be evaluated. We intend to measure and quantify a range of parameters under both treatments. These include water and nitrate leaching below the root zone of trees, possible salinity build up, tree fertilizer N uptake, and tree growth. We will evaluate the possible benefits (e.g., reduced nitrate leaching) of suggested irrigation/fertigation scenarios by HYDRUS model against the disadvantages such as costs of adding to the number of irrigation/fertigation events. Additionally, we will make use of calibrated models to run scenario analysis for other orchards, other soils, other root types. This will provide a comprehensive data set and a general guideline for application and possible benefits and disadvantages of nitrate-sensitive salinity management across the state.


G. Budget Narrative

a. Personnel Expenses.

Funds are requested for a 50% PostDoc, Maziar Kandelous, $21,420 in year 1, $22,491 in year 2 $23,616 in year 3, $24,796 in year 4 and $26,036 in year 5; with $3,749 benefits in year 1, $4,161 in year 2, $4,487 in year 3, $4,835 in year 4 and $5,207 in year 5. The benefit rate for the first 6 months is 17%, 18% for the next 12 months, 19% for the next 24 months and 20% for the duration of the grant period for a total of $118,359 in salary and $22,439 in benefits. Additional funds are requested for 50% Jr. Specialist, $19,127 in year 2, $20,083 in year 3, $21,087 in year 4 and $22,142 in year 5; with $7,479 benefits in year 2, $8,093 in year 3, $8,751 in year 4 and $9,454 in year 5. The benefit rate for the first 6 months of year 2 is 38.5%, 39.7% for the next 12 months, and 40.9% for the next 12 months, 42.1% for the next 12 months and 43.3% for the last 6 months for a total of $82,439 in salary and $33,778 in benefits. Maziar Kandelous will be the primary responsible for the project management, installations, data analysis, and writing reports and publications. The Jr. Specialist will be
responsible for the sampling, maintenance, and analyzing the collected samples.

b. **Operating Expenses.**

Funds are requested for lab supplies, soil and plant analysis to the amount of $46,880, $14,400, $11,600, $8,200 and $4,000 for the years 1, 2, 3, 4 and 5 respectively. In the first year, $46,880 is requested for experimental setup and instrumentation of the rooting zone by soil tension, soil moisture, and soil salinity sensors as well as nitrate sampling instruments. For the year 2, $6,400 is needed for sample analysis and $8,000 is needed for plant tissue analysis. In year 3, $3,600 is needed for sample analysis and $8,000 is needed for plant tissue analysis. In year 4, $3,200 is needed for sample analysis and $5,000 is needed for plant tissue analysis. In year 5, $1,000 is needed for sample analysis and $3,000 is needed for plant tissue analysis. $1,080 per year starting in year 2 and a total of $4,320 is requested for travel costs associated with participation in FREP meetings and demonstrations for the growers. Each of years 2-5 require 3 overnight trips including hotel costs ($100 per night), meals ($80 per trip), and transportation costs via car ($180 per trip). Indirect costs are requested for University of California Davis at the rate of 10% of personnel costs annually with an amount of $2,517, $5,326, $5,628, $5,947 and $6,284 for years 1, 2, 3, 4 and 5 respectively and a total of $25,701.
References: