A. **Cover Page**

University of California

Division of Agricultural Sciences

PROJECT PLAN / RESEARCH GRANT PROPOSAL

CDFA Fertilizer Research & Education Program

Project Title: Optimizing the Use of Groundwater Nitrogen for Nut Crops

AES/CE Workgroup/Departments:

Department of Viticulture & Enology
Department of Plant Sciences
Department of Land, Air and Water Resources
College of Agricultural and Environmental Science, UC Davis.

Project Years: 2013-2015 Anticipated Duration of Project: Three Years

Project Leaders:

Dr. David R. Smart, University of California, Department of Viticulture and Enology, One Shields Avenue, Davis, Davis CA 95616. drsmart@ucdavis.edu; phone, 530-754-7143; facsimile, 530-752-0382; mobile, 530-574-3929.

Dr. Patrick Brown, University of California, Department of Plant Sciences, One Shields Avenue, Davis CA 95616. phbrown@ucdavis.edu; phone, 530-752-0929; mobile, 530-304-1390.

Dr. Thomas Harter, University of California, Department Land, Air & Water Resources, One Shields Avenue, Davis CA 95616. thharter@ucdavis.edu; phone, 530-752-2709; facsimile, 530-752-8577.

Dr. Jan Hopmans, University of California, Department Land, Air & Water Resources, Davis CA 95616. jwhopmans@ucdavis.edu; phone, 530-752-3060.

Cooperators:

Blake Sanden, Cooperative Extension Kern County, 1031 South Mount Vernon Avenue Bakersfield,CA 93307. blsanden@ucdavis.edu; phone, 661-868-6218; facsimile, 661-868-6208.

Allan E. Fulton, Cooperative Extension Tehama County, 1754 Walnut Street, Red Bluff, CA 96080. asfulton@ucdavis.edu; phone, 530-527-3101; facsimile, 530-527-0917.

Maria del Mar Alsina Ph.D. University of California, Department of Plant Sciences/Department of Viticulture and Enology, Davis CA 95616. mmalsinamarti@ucdavis.edu; phone 530-219-7366; facsimile, 530-752-0382.

Project location:

Research orchards in hydrogeologic vulnerable areas: San Joaquin Valley, eg. Stanislaus, Merced, and Fresno Counties; and Tulare Basin, eg. Kings, Tulare and Kern Counties. Sites will be selected in coordination with stakeholders post-award to meet ideal criteria for soil type, hydrologic parameters, irrigation system, grower participation, orchard age and productivity, suitability for long term monitoring-well location and suitability for demonstration purposes. Correct site selection is critical and will be a first objective.

Project duration: Three years

Description of target audience:

California growers of 1.3 million acres of almonds, pistachios , walnuts, and other N-intensive perennial crops in the California Central Valley, Farm Advisors, Consultants, Fertilizer Industry, California Regulatory Organizations.

Funding Request:

CDFA FREP: 2013: $131,595, 2014: $181,751, 2015: $159,384. (Note: this request represents a multidisciplinary project proposal to ensure integration of results and to gain efficiencies for critical information).

Matching Funding:

California Pistachio Research Board, 2013: $126,985. 2014: $18,425, 2015: $19,085.
Almond Board of California, 2013: $110,235, 2014: $16,425, 2015: $17,085.

The Almond Board, California Pistachio Research Board and SureHarvest have provided strong letters of support and envision this project as an integral part of their ongoing efforts to develop grower friendly and environmentally sound N management practices. A commitment to pursue additional funding has been reached but could not be finalized before this deadline. Additional funding to establish the proposed sites as ILRP monitoring sites will be pursued.

Other Funding for Related Research not directly funding this proposal: The results and activites of several ongoing projects will be used to inform this project and strenghten outcomes of each independently and collectively. This current project represents an ideal opportunity to replicate at additional sites, to implement recent findings, and to develop new technologies.

1) D.R.Smart/Blake Sanden, "N-loss During High Frequency Low Nitrogen Fertigation", addresses soil NO_3^- absorption by tree crops from dilute N solutions and N-loss (Almond Board of California, $40,000, 2013). 2) P.H. Brown, "Development of Leaf Sampling and Interpretation Methods and Development of a Nutrient Budget Methods in Almond", provides background information on nutrient budgets and sampling methodologies to be field tested in this proposal (FREP, $65,000, 2013). 3); NewFields Agricultural Service/D.R. Smart/Applied Geosolutions LLC, "Carbon Dynamics of Orchard Floor Applied Chipped Almond Prunings", conducts statewide grower survey about the extent of the practice of pruning, quantities returned to the orchard floor and parameterization of the DeNitrification DeComposition model (DNDC), provides information critical to N budgets (California Specialty Crops Block Grant Program, $304,000, 2010-2013). 4) "Determination of Root Distribution and Physiological Parameters of Nitrogen Uptake in Almonds to Optimize Fertigation Practices", supplemental research to characterize root distribution and uptake patterns, new project will directly utilize this information and replicate across sites. (FREP, $45,000, 2013). 5) T. Harter/T. Tomich/M.H. Zhang/G.S. Pettygrove, "Nitrogen Fertilizer Loading to Groundwater in the Central Valley", develops N loading estimates for the Central Valley commodities from nitrogen flux mass balance, (FREP, $150,000 2012-2014).

B. **Executive Summary:**

The problem of nitrogen loss to air and water is currently one of the most important challenges to environmental sustainability for California agriculture, and multi-disciplinary approaches will be needed to help resolve this problem. Information is needed to inform and satisfy impending regulatory demands and to provide growers with improved management tools. Nitrate (NO_3^-) is the primary contaminant of well waters and contamination of water is reported to be "overwhelmingly the result of crop and animal agricultural activities" (Viers et al. 2012), particularly the application of synthetic fertilizers to irrigated crops. Nitrate present in groundwater (GWN) is a potential source of N for crop use, and can potentially reduce fertilizer costs, reduce N concentrations in irrigation water and hence reduce N loading to the environment. The goal of this project is to validate, demonstrate and optimize the utility of GWN and validate the 'pump and fertilize' (P&F) approach for integrated N management in Almonds and Pistachio in a vertically integrated, multidisciplinary project.

The P&F approach rests upon the assumption that a pound of nitrate in groundwater is equivalent to a pound of properly managed nitrogen from fertilizer. On a purely chemical basis, this assumption is correct, in the context of orchard nutrient supply however, this assumption may not be biologically or functionally valid since GWN will often be applied at lower concentrations and at different phenological stages than well managed N fertilizers would be. Further, while the timing of N application during the year and during a fertigation event can be controlled by the grower, GWN will be delivered according to irrigation schedules and will generally be uniform through all irrigation events and thus may be differentially susceptible to leaching loss. Soil properties, irrigation management, crop nutrient status, and crop demand can all interact to alter these dynamics.

To optimize the beneficial uses of GWN, we must first determine: 1) the relationship between soil solution NO_3^--N concentration and root uptake at different stages of crop phenology and crop N demand and 2) experimentally measure and simultaneously model the effects of N delivery source and irrigation method on NO_3^- retention in the root zone. The knowledge obtained in 1) and 2) must then be integrated with best available models of crop nutrient demand, climate dependent irrigation practice, soil properties and grower management so that delivered N meets crop demands and N is retained in the crop root zone with maximum absorption and assimilation. 3) To be accepted as a viable strategy, the P&F principle must also be convincingly demonstrated and proactively extended to growers, 4) There is a need for development of monitoring technologies that are practical and provide real time feedback to growers and can be correlated with information from of long-term groundwater monitoring wells, to reduce the possible reliance on wells as the feedback mechanism.

Several completed and ongoing CDFA, Almond Board, and USDA funded projects held by the PI's on this grant will provide critical data for this project. These include 1) development of annual nutrient demand budgets for Almond and Pistachio, 2) determination of root distribution and root nitrate uptake in Almond, 3) development of early season nutrient monitoring for Almond and Pistachio. The current proposal utilizes the following objectives to validate, adapt and extend current best practice and new findings to the P&F context. The objectives are:

1) Establish research and demonstration orchards for "Advanced Grower Practice" and "Pump and Fertilize" nitrogen management in Almond and Pistachio within "Hydrogeologically Vulnerable Areas" (HVAs)
2) Utilize and validate recent developments in yield and nutrient budget N management, early season sampling and yield estimation to describe best management practices and contrast those practices with 'Pump and Fertilize' N management treatments.
3) Characterize key biological and physical parameters relevant to P&F concept (concentration dependent uptake, root distribution and activity, phenology of uptake, seasonal plant-soil N balance, soil NO_3^- movement etc).
4) Establish proof of concept for use of stable isotopes of $^{15}NO_3^-$ in N tracing under P&F practices.
5) Develop and ground validate decision support models (including Hydrus) to assist growers with optimal management of groundwater nitrogen.
6) Demonstrate and proactively extend developed results, technologies and BMP's to growers.

We will select two almond and two pistachio orchards within identified "Hydrogeologically Vulnerable Areas" (HVAs). The will include key climatological and soils differences that will have potentially significant effects on nitrate control and leaching.

C. **Justification**

1. Problem: Over 30 million California residents (about 85%) rely partially or fully on groundwater as a source of drinking water (SWRCB, 2012). Nearly 2,600 California communities rely on about 8,400 community public supply wells as the main source of their drinking water. Among these, 1,662 public supply wells in 682 California communities are contaminated, and in one-third of these communities due to nitrate pollution alone (206 communities with 452 nitrate contaminated wells). This does not include private domestic households or households on state-small and local public water systems (2-14 connections), of which as many as 40% may be contaminated with nitrate (Boyle et al., 2012). In regions with predominantly agricultural land use, such as the Central Valley and the Salinas Valley, over 90% of groundwater nitrate pollution is estimated to originate from agricultural lands (Harter et al., 2012). Improved water and nutrient management practices would lead to significantly lower groundwater nitrate pollution. These practices must also account for non-fertilizer sources of nitrogen, such as irrigation water nitrogen and soil amendment nitrogen, (Dzurella et al., 2012). Few studies have considered managing nitrate in irrigation water ("pump and fertigate"), but in one example it was found that replacement of commercial fertilizer with irrigation water NO_3^- was effective at a 1:1 ratio or better (King et al., 2012).

There is a need to develop an understanding of the utility of groundwater nitrate as a source of N for nut crops and to field demonstrate this practice so that guidelines for grower implementation can be developed and extended.

2. CDFA/FREP goals: FREP is seeking research to further elaborate on the use of irrigation water NO_3^- as part of a grower's nutrient management planning and to identify at what rate irrigation water NO_3^- may replace commercial fertilizer under optimal water and nutrient management practices. To achieve this goal we must determine: 1) the relationship between soil solution NO_3^--N concentration and root uptake at different stages of crop phenology and crop N demand and 2) experimentally measure and simultaneously model the effects of N delivery source and irrigation method on NO_3^- retention in the root zone, and 3) integrate these results with best available models of crop nutrient demand, climate dependent irrigation practice, soil properties and grower management so that the combined GWN and fertigated N meets crop demands and N is retained in the crop root zone with maximum efficiency .

3. Impact: This research will provide growers with information needed to quantify and optimize the use of GWN for nut crops. Use of GWN as a part of a trees annual N budget has the potential to reduce NO_3^- loading to groundwater. An added benefit may be to to save growers money. The research performed will provide critical information to the Central Valley Regional Water Quality Control Board under the current draft waste discharge requirements for their Irrigated Lands Regulatory Program:

http://www.swrcb.ca.gov/rwqcb5/water_issues/irrigated_lands/long_term_program_development/eastern_sanjoaquin_watershed_wdrs/index.shtml.

Specifically, this research program has the potential to contribute to a Central Valley wide "representative groundwater monitoring program" as outlined in Attachments A and B to the tentative Waste Discharge Requirements for the Eastern San Joaquin Watershed and to the draft Waste Discharge Requirements for the Tulare Lake Basin area:

http://www.swrcb.ca.gov/rwqcb5/water_issues/irrigated_lands/long_term_program_development/tulare_lake_basin_area_wdrs/index.shtml.

In addition, this research has the potential to develop viable alternative methods of monitoring the effect of management practice on nitrate leaching. In contrast to monitoring wells, methods such as lysimeters, tensiometers, soil sampling and modeling provide a more time and management sensitive measure of real time and local nitrate fluxes. Information of this kind will provide growers with much needed feedback on their management decisions and thus improve decision making. The overall objective of a representative groundwater monitoring program is to establish a clear link between nitrogen budgets (nutrient management) for a specific crop and management practice and to view the resulting actual groundwater NO_3^- loading.

Our proposed field scale research sites with their intensive plant, soil root zone, and groundwater monitoring networks will identify the pathways and fluxes of nitrogen, including annual groundwater NO_3^- loading, as a function of the N budget and nutrient management in Almond and Pistachio. The proposed research would therefore be a key candidate to be included in the representative groundwater monitoring program currently being drafted by the regulatory agencies in collaboration with the agricultural coalitions in order to identify representative monitoring approaches. The research conducted here will provide the scientific underpinning for using NUE as a key measure in meeting the Waste Discharge Requirements to supplement the more expensive and less responsive groundwater monitoring for orchard growers.

The sites used in these experiments will be principle demonstration sites for Pistachio and Almond industry field days demonstrating both the P&F principle and also as sites to demonstrate new applications of nutrient budget management and leaf sampling, and as demonstration sites for new technologies.

4. Long-term solutions: Over the long term, the developed nitrogen recommendation models will help to control N losses to groundwater and, by reducing NO_3^- concentrations in groundwater will contribute to the restoration of below ground California water sources to concentrations below the US EPA's recommended hazardous NO_3^- concentration.

Improved nitrogen management practices in California orchards will improve NUE thus decreasing the economic and environmental cost of over fertilization. Any new tool that is able to better predict the N needs of orchards represents a positive economic and environmental impact in the California. Demonstrating and optimizing the use of groundwater NO_3^- for nut crops is essential if this approach is to be widely adopted.

5. Related research: Optimal fertilization practices can only be developed if knowledge of the 4 R's (right source, right rate, right place, and right time) are explicitly developed for the almond and pistachio (and other tree crops) production context. To optimize NUE, whether from groundwater or fertigation, it is essential that N injected into irrigation systems are provided at the optimal concentration and time to ensure that deposition patterns coincide with maximal root nutrient uptake. To achieve this, and to estimate efficiencies, a detailed understanding of the plant and the soil and hydrologic properties governing NO_3^- fluxes is needed.

Recent FREP, Almond and Pistachio funded projects to the PI's on this grant have resulted in advances in nutrient budgeting and nutrient status determination. A second FREP and Almond Board funded activity is providing information on the patterns of root growth and the patterns of NO_3^- (and NH_4^+) uptake by almond during the year as affected by differential N application rates and timings. These technologies will be applied to this new site so that they can be further validated and used to both optimize mineral-N use and demonstrate new technologies. In addition, the Almond Board has funded a project to develop and validate the Hydrus modeling effort to the Almond context. Initial results suggest that Hydrus can be very effectively used to determine and predict (and hence manage) the flux of NO_3^- through the soil profile. The current Almond funded activity is the first occasion where this technology has been examined in an intensive integrated project. The project proposed here will add four additional experimental sites representing a significant proportion of the almond and pistachio production areas. Hydrus will be further refined and simplified with the goal of identifying the most critical parameters and measurement techniques, to develop a broadly applicable and easily implemented tool for integrating plant demand dynamics with soil flux principles to ensure N is available at optimum concentrations in the root zone with minimum leaching potential.

In order to define the right annual nutrient demand it's crucial to know the general pattern of N uptake by the tree, which is directly dependent spatial and temporal distribution of the nutrient and active roots in the soil profile, seasonal crop nutrient demand patterns, and root uptake characteristic. This information must then be integrated with fertigation system design, soil type, and groundwater or fertilizer N source to maximize the efficiency of fertilizer use. Our first efforts to solve this complex issue (CDFA 2012-2013) are already demonstrating that the concentration of NO_3^--N applied during a fertigation (or groundwater N application) event influences the efficiency with which that N is used. Root N uptake at a certain point in time is also strongly affected by the previous N inputs to the system (Fig 4), and suggests that low N concentrations when applied over extended times are efficiently used and canminimize soil NO_3^- concentration. These findings are preliminary from one site, and results canl be further validated and refined in the proposed project.

In five prior years of experimentation at 6 sites statewide, we have established a strong understanding of annual N allocation and accumulation in both Almond and Pistachio. Patterns of N accumulation and the relationship of yield and tree N status on tree N dynamics under various N treatments have been utilized to establish a robust estimate of tree N dynamics (project reports to CDFA-FREP, Pistachio Research Board and Almond Board are available upon request and are summarized at http://ucanr.org/sites/scri/). Several key results are provided below.

Pattern of N accumulation in trees

Figures 2 and 3 show patterns of N accumulation in fruits over the course of the year until harvest. Leaf N in Almond (10-15 lbs/acre) and Pistachio (15-35 lbs/acre) is not included in this budget since these quantities are small in contrast to fruit accumulation and further, the majority of leaf N is recycled within the tree and soil and hence does not constitute a net N cost.

The majority of N accumulation (80%) occurs between flowering and fruit maturity in August (almond) and September (Pistachio). In adequately fertilized trees N off-take in all harvested fruit parts is 62 +/- 4 lbs N/acre (1000 lb kernel yield) and 28 +/-6 lb (1000 lb CPC equivalent). Fruit yield is by far the greatest determinant of N demand in nut crops. The validity and site specificity of these estimates will be further tested in the proposed project.

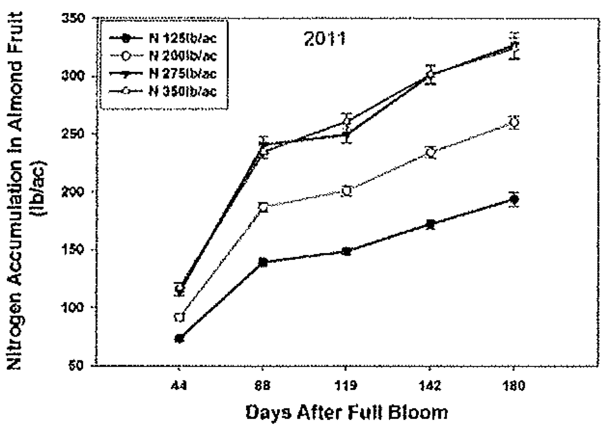


Figure 2. Nitrogen accumulation in fruits in Almond trees (Kern County) over time.

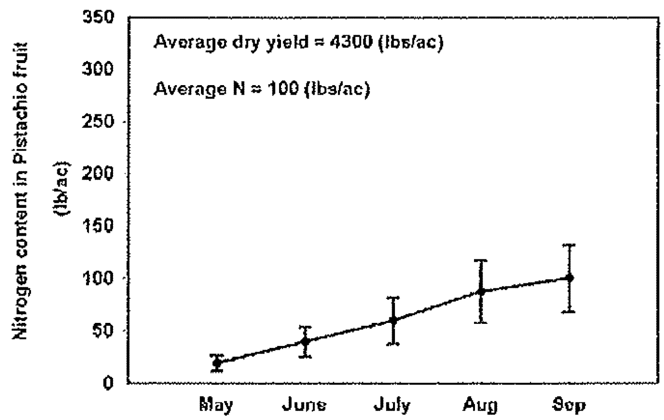


Figure 3. Nitrogen accumulation in Pistachio fruits ~~in~~(Kern County) over time.

While total N accumulation in nuts (Figures 2 & 3) is the most important determinant of N demand, this data alone is not adequate to determine when uptake occurs from the soil. To better understand that dynamic, N content in all perennial tissues is currently being determined. Preliminary results are shown in Figure 3. Here the nutrient content in the standing biomass was determined by sequential tree excavation and by drilling cores into wood tissues monthly throughout the season. Analysis was conducted on trees differing in N application rates.

Data suggests that large roots (>1 cm diameter) and canopy branches represents the largest pool of N in the orchard (data not shown). The fraction of that N that is available for use in growth is estimated from the difference between the highest annual N content and the lowest. Data from trees that received 275 lbs/acre is most relevant as those trees were adequately but not excessively fertilized as indicated by yield and tissue N concentrations. Differences between maximal (January 26 – full bloom) and minimum (March 12 – 70% full leaf expansion) whole tree N content in perennial tissues was estimated at 40 lbs N per acre. During this period an estimated 30 lbs N has been assimilated into leaves and fruits with an unknown, but undoubtedly small (<3 lb) amount of N lost in flowers and an unknown quantity lost due to root turnover. These preliminary results indicate that N uptake from soil does not occur before mid-late March (full leaf out). This data will be verified in the proposed project and represents a critical component of the overall N budgeting and flux determinations.

Knowledge of the exact timing and mass balance of N demand is essential to interpret the relative efficacy of groundwater N use. The proposed project will add a new layer of complexity and refined efficiency of mass balance in bringing in the pump and fertilize concept and therefore adding a second source of N input for mass balance knowledge base.

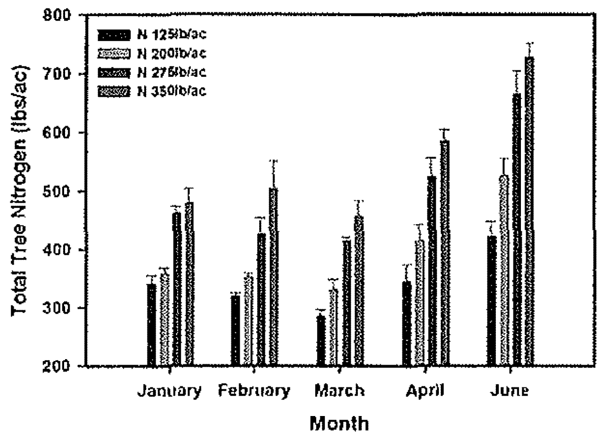


Figure 3. Nitrogen content (lbs/acre) per tree, standing biomass including fruit.

Influence of Tree N status on Root N determinations

In early January dormant intact roots on intact trees in the field were placed into root growth bags. In mid-May roots were excavated and used in in-vitro nitrate uptake experiments. Roots from trees of differing N status were harvested and exposed to different NO_3^- concentrations (Fig 4). Nitrogen uptake is strongly affected by tree N status. Roots excised from trees under the lowest fertilization treatment showed a significantly higher nitrate uptake from the most diluted NO_3^- solutions than roots from well-fertilized trees. At high NO_3^- application rates (14 ppm) roots from the highest N pretreatments had higher net uptake rates. This suggests that tree N status alters tree uptake capacity and demonstrates effective nitrate uptake from low soil solution nitrate concentrations

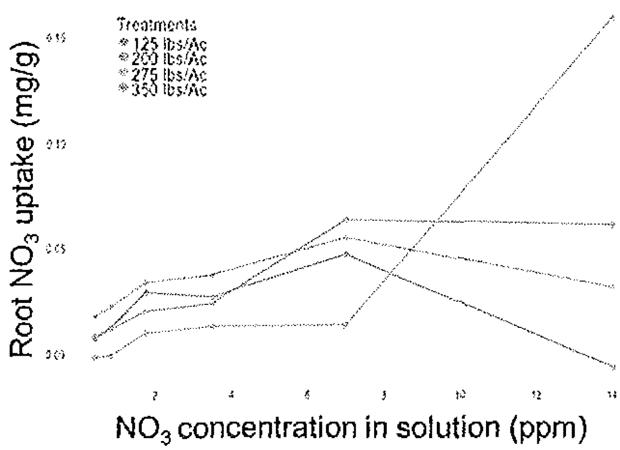


Figure 4. NO_3^--N uptake by excised almond roots at different external concentrations

Because of the importance of tree N status on N uptake potential it is important to get an early indication of tree N status. In CDFA funded research we have now demonstrated that early April leaf analysis can accurately predict July nitrogen content in leaves. This new sampling method will be integrated with crop yield estimates to fine tune N budget recommendations in the current proposal (Saa-Silva *et al.*, 2012).

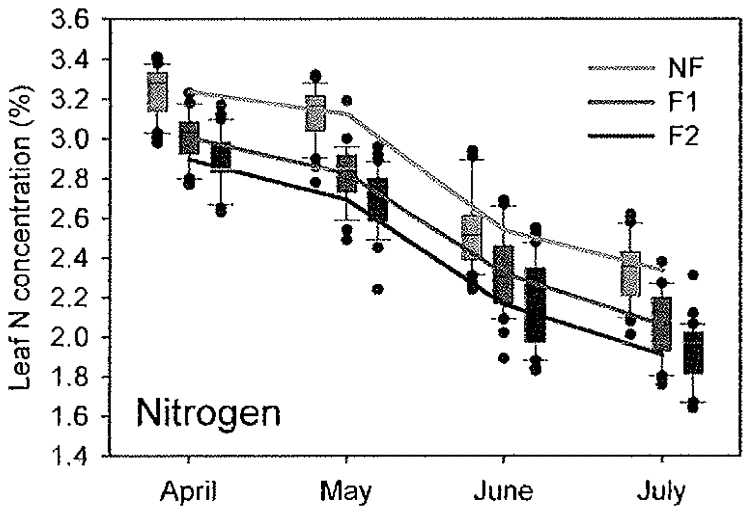


Figure 5. Leaf Nitrogen concentration through the season in leaves from non-fruiting spurs (NF), spurs with 1 fruit (F1), and spurs with 2 fruits (F2)

Other than leaching, N can be directly lost from the soil to the atmosphere as NO_x, N_2O and N_2, the major gaseous products of denitrification (and nitrification) by soil bacteria. The activity of nitrifier and denitrifier microorganisms is affected by the N availability and soil water content among others. As a direct consequence of this, the use of microsprinkler irrigation versus drip irrgation and calcium ammonium nitrate versus Urea as N source showed to decrease significantly the N_2O-N emitted at orchard level. This knowledge base acquired during 2009 to 2012 by one of the PIs (Schellenberg et al. 2011; Alsina et al. 2012) will be extremely useful in the selection and application of fertilizer N in the proposed project.

D. Objectives

1) Establish a series of research and demonstration sites in Almond (3) and Pistachio (3) within two "Hydrogeologically Vulnerable Areas" (HVAs)
2) Utilize and validate recent developments in yield and nutrient budget N management, early season sampling and yield estimation to describe best management practices and contrast those practices with 'Pump and Fertilize' N management treatments.
3) Characterize key biological and physical parameters relevant to P&F concept (concentration dependent uptake, root distribution and activity, phenology of uptake, seasonal plant-soil N balance, soil NO_3^- movement etc).
4) Establish proof of concept for use of stable isotopes of $^{15}NO_3^-$ in N tracing under P&F practices.
5) Develop and ground validate decision support models (including Hydrus) to assist growers with optimal management of groundwater nitrogen.
6) Demonstrate and proactively extend developed results, technologies and BMP's to growers.

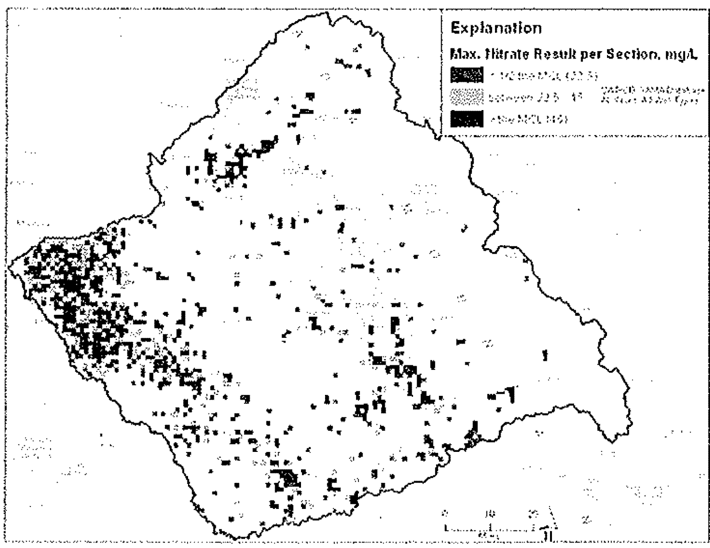
E. Work Plan and Methods

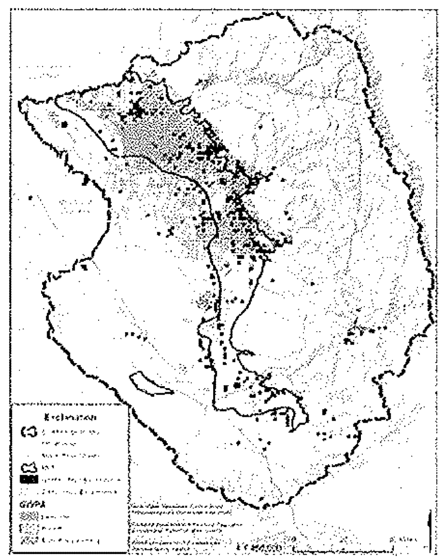
1. Overarching Concept Design and Anticipated Tasks

The overarching design consists of selecting two almond orchards and two pistachio orchards in "Hydrogeologically Vulnerable Areas" (HVAs) and where well water indicates moderately high levels of NO_3^- contamination. A third orchard at each location will be selected to establish a replicated experiment to contrast Advanced Grower Practice, Pump and Fertilize and a third treatment to be determined in collaboratioin with stakeholders. Almond and pistachio and similar N-intensive fruit and nut crops like other *Prunus* cultivars and walnuts comprise over 1.5 million acres (NASS, 2010) with the largest acreage predominantly within the Central Valley and a large acreage in particular for almond and pistachio within identified HVAs (Harter et al. 2012). The focus here is on almond and pistachio due to their importance. Almonds and pistachios offer contrasting phenologies and N demands which will allow for determination of general principles applicable to tree crops.

1. 1 almond orchard under P&F, intensive hydrologic monitoring, N mass balance.
2. 1 almond orchard, AGP and intensive hydrologic monitoring, N mass balance.
3. 1 pistachio orchard, P&F and intensive hydrologic monitoring, N mass balance.
4. 1 pistachio orchard, AGP and intensive hydrologic monitoring, N mass balance.
5. 1 almond orchard, 3 factor design to contrast P&F, AGP and TBD, yields & N mass balance.
6. 1 pistachio orchard, 3 factor design to contrast P&F, AGP and TBD, yields & N mass balance.

The State Water Resources Control Board created a map in 2000 showing locations where hydrogeologic conditions are vulnerable to contamination of groundwater. Sites will be chosen from within these regions. Selection of the research sites is of paramount importance and must consider many variables (specified below). Sites must then be pre-sampled to ensure they meet all parameters for technical suitability, relevance, and utility as demonstration sites for field days and other extension activities. For this reason Objective 1 is focused exclusively on site selection, preliminary testing, and installation of equipment. This activity will be commenced immediately upon grant funding.





Objective 1. Establish the above research and demonstration sites in almond and pistachio within the two identified "Hydrogeologically Vulnerable Areas" (HVAs) (Tasks 1 to 4).

Tasks 1-4: January, 2013 to December 2013.

Task 1: In collaboration with FREP, Almond Board, Blue Diamond Growers, Pistachio Research Board and grower collaborators we will select experimental sites within the HVAs with the required characteristics discussed in section E2.

Task 2: We will conduct preliminary site sampling to gather information on well water NO_3^- concentrations and if sites are appropriate undergo mapping and hydrologic flow assessments.

Task 3: The research sites will be equipped with intensive monitoring stations to allow for a thorough assessment of soil moisture movement, and of nitrogen fate and transport from application, through the root zone, and into crops and to shallow groundwater. The design consists of three monitoring systems:

- Nitrate concentration measurements in 3 sets of 12 lysimeters per treatment, where each set is installed at different depths (shallow root zone, deep root zone, below the root zone).

- Water and nitrogen flux monitoring in intensely monitored tree site utilizing soil moisture probes, direct soil sampling, and tensiometers.
- Shallow groundwater monitoring wells representative of the recharge from the respective treatment will be installed. Groundwater monitoring wells will be drilled using continuous coring techniques, and designed to have a source area of several hundred feet in length and to capture representative recharge from the immediately upgradient treatment field site. Groundwater well location will depend on regional groundwater flows, which will be assessed using water level data available from CaDWR and USGS.

  The research site and monitoring protocols developed here are intended to be compatible with future requirements of the Central Valley Regional Water Board conditional waiver for irrigated lands, which requires a "representative monitoring program" as a key part of future water quality protection. The colocation of 'certified' monitoring wells with the alternative approaches (nutrient budget, Hydrus modeling, direct soil and soil solution sampling) represents a powerful mechanism to cross validate technologies and develop alternative, grower relevant N management and monitoring strategies.

  Task 4: Install needed irrigation modifications in the experimental sites.

Objective 2. Utilize, validate and demonstrate recent developments in yield and nutrient budget N management, early season sampling and yield estimation to prescribe best management practices and contrast those practices with 'Pump and Fertilize' N management treatments. (Tasks 5 to 7).

Task 5-7: January, 2013 to September 2015.

Task 5: In collaboration with growers we will establish fertigation regimes that incorporate an 'Advanced Grower Practice' treatment and a Pump and Fertilize regime that incorporates and accounts for the concentration of GW NO_3^-. The treatments will utilize advances in management derived from current FREP, Almond, and Pistachio funded research, and serve as a ground validation and source of additional information for ongoing refinement, but contrast P&F with an AGP that does not account for GW NO_3^-. Fertilization rates and timings will be based upon yield expectations, prior and current years leaf, wood and soil tissue sampling.

Task 6: Monitor leaf, wood and fruit nutrient status during the season and measure yields in the experimental sites. Monitor orchard leaf area and phenology.

Task 7: During the third year, this information along with objective 3 results, will be used to validate and/or modify the established relationships between yield and tree, soil and climatic characteristics from previous projects (section 3.5). The outcome will be an improved Nutrient budget and early season sampling strategy to optimize N use efficiecenies.

Objective 3. Characterize key biological and physical parameters relevant to P&F concept (concentration dependent uptake, root distribution and activity, phenology of uptake, seasonal plant-soil N balance, soil NO_3^- movement etc). (Tasks from 8-10)

Task 8-10: January, 2013 to September 2016.

Task 8: Determine root distribution patterns and water and N parameters and responses. Characterize root growth distribution and N uptake parameters at the field sites. Studies to be pursued through other funding sources.

Task 9: Measure soil water nitrogen and salts, and moisture levels at various depths. Parametize all aspects of Hydrus model.

<u>Objective 4: Establish proof the concept for use of stable isotopes of $^{15}NO_3^-$ in N tracing under P&F practices. (Tasks from 11-12)</u>

Task 10-12: January, 2013 to September 2016.

Task 9: During the first year, the isotopic ratio of natural abundance $^{15}N/^{14}N$ levels (‰) will be determined for all end member sources (fertilizer, soil NO_3^-, aquifer NO_3^-) in order to determine rates and quantities of NO_3^- moving in the system.

Task 10: During the second year and using information gathered from the isotopic ratio of natural abundance $^{15}N/^{14}N$ levels (‰) in Year 1 for all end member N-sources (fertilizer, soil NO_3^-, aquifer NO_3^-), root zone soil water, and plant tissues (samples collected for objectives 2-3 above) will be analyzed to establish rates and sources of NO_3^- movement through the rooting zone.

Task 11: During the third year, we will gather a second season of data as per Year 2,making adjustments to the experimental design based upon the first two years of data.

<u>Objective 5: Develop and ground verify decision support models (including Hydrus) to assist growers with optimal management of groundwater nitrogen. (Tasks from 14-15)</u>

Task 13-14: December, 2013 to September 2016.

Task 12: Run HYDRUS-2D/3D simulations with the inputs derived from current Almond Board funded project. Validate and optimize the model output with field measurements derived from Objectives 2 and 3.

Task 13: Couple HYDRUS model outputs with nutrient budget outputs utilizing an existing optimization model (MATLAB).

<u>Objective 6: Demonstrate and proactively extend developed results, technologies and BMP's to growers.</u>

Note: we have a strong commitment from Almond Board, Blue Diamond Growers and Pistachio Board to support, manage and fund the grower extension and demonstration activities associated with this project. This activity will inform the Almond Board/SureHarvest Almond Sustainability Program. It is expected that these sites will become a part of the ILRP monitoring sites and as such will have very high visibility and relevance.

Task 14-17: October, 2014 to December 2016

Task 14: Present the first results and experimental principles and project goals at grower and other stakeholder meetings (possible meetings include FREP, WPHA, Agronomy Society, regional commodity meetings etc.). Prepare educational 'WebCast' video explaining the project. Construct project website.

Task 15 (Year 2 and 3): In collaboration with Almond Board and Pistachio Research Committee and Farm Advisors from relevant districts, organize 2 or more "field days" to present the new findings to growers, explain how to use the developed models for nutrient decision, illustrate and demonstrate P&F approach, and present preliminary outcomes.

Task 16 (Year 3): Coordinate web and paper publications in grower and peer reviewed journals. Prepare technical summary for use by commodity boards, water boards and other agencies.

Task 17 (Not funded by this proposal): It is envisioned that outcomes from this project, in coordination with other relevant ongoing projects will be integrated into the Agricultural Sustainability Programs of Almond and Pistachio industries and will be extended to stakeholders utilizing the most relevant and impactful technologies. Please see letters of support from SureHarvest, Almond Board, Pistachio Research Committee and Packard Foundation.

2. Methods

<u>**Objective 1:** Establish a series of research demonstration sites in Almond and Pistachio within "Hydrogeologically Vulnerable Areas" (HVAs)</u>

The selection of the orchards will require a survey effort that should include information about soil profile and characteristics, accessibility to contaminated water layers, etc to insure that all the orchard characteristics are adequate for the project objective and experimental needs. For this reason, the experimental sites are not selected yet. Although, we have established a detailed list of criteria for the site selection according to the experimental requirements of the specific objectives.

1) Two Sites for Each Crop (Pistachio and Almond). 1 each from within HVA's near Modesto and near Madera/Fresno/Visalia.

2) Productive and well managed orchards of adequate size (>100 acres per treatment, per replicate) for representative soil monitoring and groundwater monitoring. We will initially focus on 'prime age' orchards though having young orchards in area would allow for subsequent contrasts.

3) Availability of both consistent high N groundwater and low N surface water to allow for treatment control.

4) Highly uniform sandy or sandy/loam soils with no clay and no impermeable layers in the vadose zone or shallow groundwater.

5) Less than 30 ft depth to groundwater (no direct root access to groundwater) with relatively small water table fluctuations.

6) Highly participatory and reliable grower cooperator. Location suitable for field days and demonstration purposes.

The following is a hypothetical field design: Orchard blocks of sufficient size (eg. 80-160 acres), soil drainage characteristics, shallow GW tables to monitor first encounter of ground water and with a NO_3^- contaminated water source will be established. A similar intensive monitoring system will be set up at each site that includes the basic experimental design shown in Figure 6.

It is intended that three replicate plots will be established at each research site (two Almond, Two Pistachio). Because of the scale of these plots and the constraints that groundwater monitoring wells and site selection impose, the specifics of these plots cannot be pre-determined. It is proposed that 2 monitoring wells be placed in each treatment and a set of 12 lysimeters be placed at each of three different depths: shallow root zone, deep root zone, below the root zone. A total of 6 research orchards, each >100 aces is envisioned, preliminary sites have been identified, however ground verification and grower commitment has not been finalized.

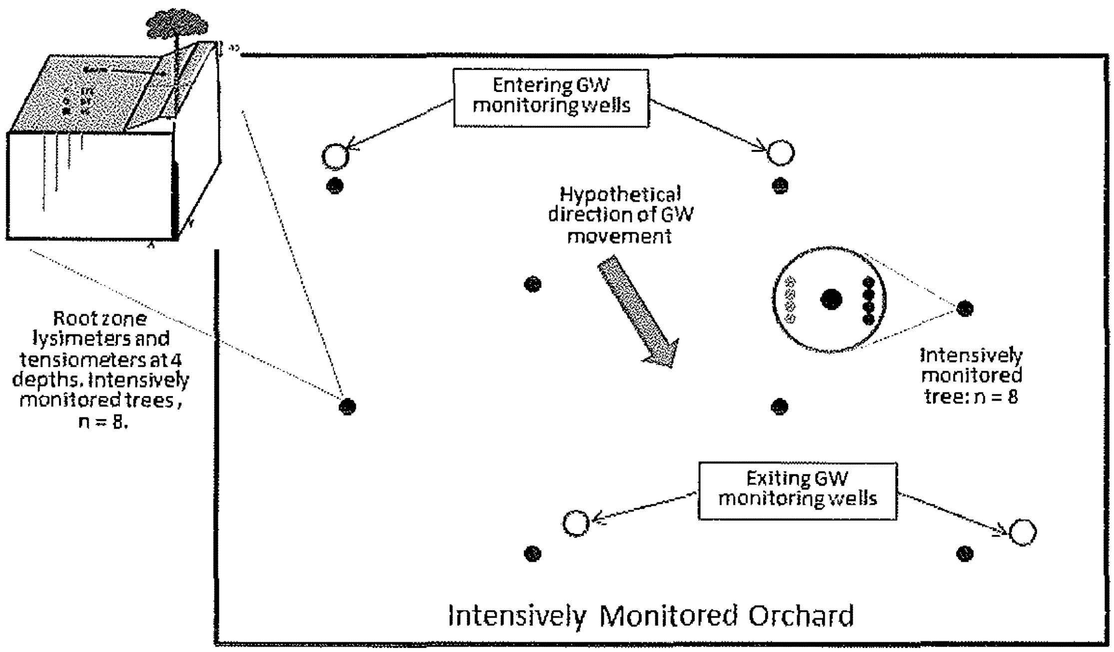


Figure 6: Shown is a concept diagram of the current experimental design for intensively monitored orchard sites, which will be subjected to advanced grower practice (AGP) and pump and fertigate (P&F) treatments for almond and pistachio. There will be 4 such orchards (n = 1) for almond (2) and pistachio (2). Red symbols represent intensively monitored trees that will be equipped with suction lysimeter and tensiometer arrays to monitor NO_3^- and water movement through the rooting zone: two such trees are illustrated to show depth and positioning of arrays. Blue open circles represent entering (n = 2) and exiting ground water (GW) monitoring wells. The large arrow indicates an example of primary flow direction of the first encountered ground water.

<u>**Objective 2**: Utilize and validate recent developments in yield and nutrient budget N management, early season sampling and yield estimation to prescribe best management practices and contrast those practices with 'Pump and Fertilize' N management and a treatment to be determined.</u>

Three treatments will be established and contrasted. The explicit details of these treatments will not be known until a grower cooperator has been identified since details of irrigation system design, water delivery schedules and flexibility, ground and surface water quality will all influence ultimate management strategies:

The following principles will be used to establish both treatments:

The N removal rate for almond is 60+/-4 lbs lbs N per 1000 lb kernel yield and for Pistachio is 28 +/-7 lbs per 1000 CPC yield. This removal rate corresponds to maximal yield and optimal use of N. Current best practices suggest 80% of nutrients should be applied during the active tree growth cycle commencing in late Spring (full leaf expansion) and continuing through mid-June. A total of 80% of the annual fertilizer should be applied in this period in a minimum of two fertigation events. An additional 20% of annual fertilizer can be provided early post harvest while leaves are still healthy. The current practice of sampling leaves in July is too late to allow for current season fertilizer adjustment, and leaf sampling alone doesn't provide sufficient information to make fertilizer recommendations. An improved method of leaf sampling and fertilizer management has been developed that utilizes April leaf sampling and yield estimates to predict N demand and allow for in-season fertilizer adjustments. These new methods will be applied to the proposed treatments (below) and will serve as a demonstration and for validation of these approaches. A contrast to normal grower practice can be conducted through sampling of plots within the growers normal production fields in a fully replicated experiment (Figure 7, n = 4).

Treatment A: Advanced Grower Practice (AGP): this treatment is designed to be both a demonstration of the most advanced nutrient management strategies and a contrast for the P&F treatment.

-N allocations will be prescribed according crop demand and the phenology of nutrient uptake from the soil. In-season monitoring of leaf nutrient status and yield will be utilized to allow for in-season adjustment of fertilizer schedule.

-N applications as fertilizer N (CAN and UAN 32 with ratios designed to match nitrate/ammonium/urea concentrations in treatment B) will be established to equal 120% of estimated annual N removal and allocated according to site specific phenology in three or four fertigation events (determined by grower specific conditions).

Treatment B: Pump and Fertigate: (this treatment is a modification of treatment A with incorporation of GWN into N budgets).

-N allocations will be prescribed according to crop demand and the phenology of nutrient uptake from the soil. In season monitoring of leaf nutrient status and yield will be utilized to allow for in-season adjustment of fertilizer schedule.

-N applications will be established to equal 120% of estimated annual N removal and allocated according to site specific phenology in three or four fertigation events (determined by grower specific conditions). Application of fertilizer N will be offset by the mass of N that has been delivered to the site in groundwater between each fertigation event so that the total annual N allocation is identical to the AGP treatment.

-N in groundwater will be determined by real time subsampling of irrigation water during all irrigation events.

Treatment C: TBD: This treatment is being determined in consultation with a stakeholder advisory group that consists of commodity boards (almond and pistachio), fertilizer companies, the CDFA FREP and University of California participants. Proposed treatments may consist of nitrification or urease inhibitors, or both, high frequency low nitrogen fertigation (HFLN), slow release forms of N applied at a rate equivalent to that of either AGP or P&F. Current thinking is this treatment will be determined by January 1 2014, in time for implementation and contrast with AGP and P&F.

To further validate our previous developments in yield and nutrient budget management and provide site specific data we will conduct leaf, nut, and canopy sampling at several times during the season, and at harvest (Schellenberg et al. 2011). At the individual tree/orchard level leaf and nut samples from 4 quadrants of canopy heights of 6 trees will be taken and analyzed for leaf mass (g_{leaf}) nitrogen content (N_{leaf}, unitless g g^{-1}) and leaf area determination (A_{leaf}). This exercise provides the Specific Leaf Weight (SLW, $A_{leaf}\, g_{leaf}^{-1}$), the biomass per unit of leaf area. For each of twelve target trees, Leaf Area Index (LAI, unitless $m^2\, m^{-2}$) measures the leaf area per unit of ground area. The LAI is gathered from fisheye photographs taken at ground level, viewing up through the canopy. Equations 1 shows how these can be used to scale leaf nitrogen per unit tree and then the tree as a unit is used to scale these measurements to the orchard level:

$$N_{Larea} = SLW \times LAI \times N_{leaf} \qquad (1)$$

where, N_{Larea} is the estimated leaf nitrogen (g m^{-2}) per unit ground area of the orchard. The spatial variation caused by tree shape and planted density are accounted for when N_{area} is scaled to the orchard level (per ha,, Alsina et al. 2012). For roots N_{Rarea}, it is assumed the quantity of fine roots produced during the season is equal to the quantity of leaves produced, and then scaled to the unit tree using the accepted root:shoot ratio for tree biomass allocation (see Kroodsma and Field, 2006). For harvested nuts $N_{nutarea}$, the nitrogen content of kernels and hulls is measured from individual trees and, again, scaled to the orchard level using the individual tree as the scaling unit. For wood N_{Warea}, we have sampled extensive wood samples from increment cores and analyzed for N content and for scaling to the tree level. Prunings (N_{Parea}) can be quantified using standard litterfall traps in addition to collecting prunings from the orchard surface. One of us (Smart) is part of an effort through the California Specialty Crops Block Grant Program to acquire better quantitative estimates of pruning carbon and N content and return to the orchard floor for parameterization of the DNDC model. Equation 2 estimates the annual net primary production of N (N_{NPP}):

$$N_{NPP} = \sum NA_{orchard} \qquad (2)$$

Because lysimeters collect data relevant to the local condition of the tree under which the lysimeters are placed it is essential that trees be monitored on an individual basis. Data should then be scaled to per acre of per orchard area for use in interpreting monitoring well impacts. A multi-scaled approach is thus essential. Data collected over multiple seasons will be used to establish the relative efficacy of the "pump and fertilize" management strategy as contrasted with conventional fertilization.

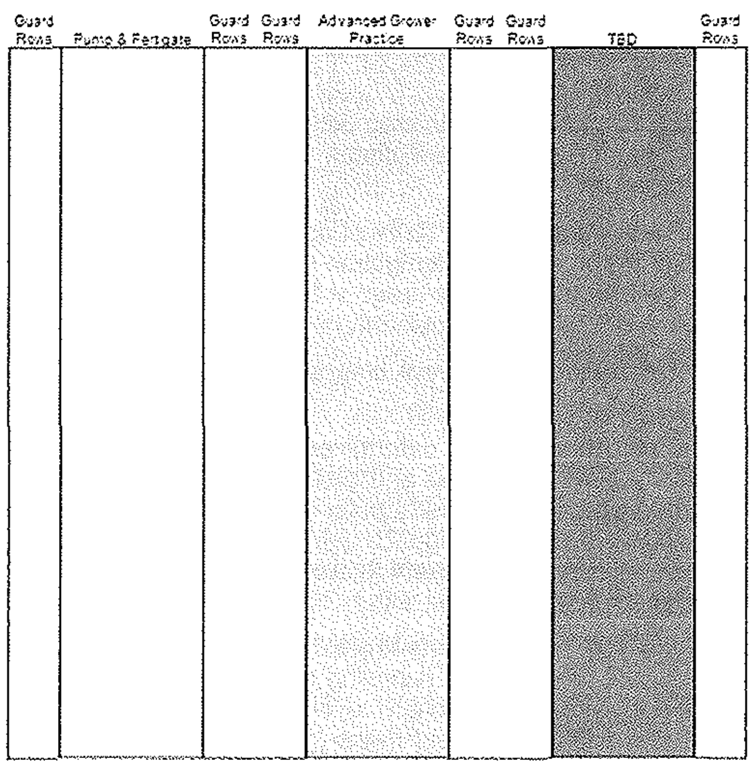


Figure 7: Shown is the proposed experimental design for contrasting N-balance for the three proposed orchard experiments of AGP, P&F and TBD. Treatments and guard rows run the length of the row to facilitate economic establishment of experiment. Shown is one replicated block (n will = 4).

Objective 3: <u>Characterize key biological and physical parameters relevant to P&F concept (concentration dependent uptake, root distribution and activity, phenology of uptake, seasonal plant-soil N balance, soil NO_3^- movement etc).</u>

In order to evaluate the Hydrus model results, additional soil data are required as inputs to the model. Selected data will be collected from each treatment of the larger experimental design. We will collect the following data for model input and model evaluations. Results on root distribution, concentration dependent root uptake parameters and root phenology and proliferation are available from other efforts carried forward by several of the participating PIs although it is acknowledged some refinement may be necessary.

(a) Soil Physical and Hydraulic Properties: A set of soil cores will be collected for each treatment/replicate, and soil texture, bulk density, soil water retention and unsaturated hydraulic conductivity data will be collected in Hopmans' laboratory using routine laboratory procedures (Eching and Hopmans, 1993).

(b) Soil water content: Soil moisture and soil temperature will be measured at 4 depth increments using ECH_2O 5-TE (Kizito et al., 2008) and MPS-1 soil sensors (Malazian et al, 2010), for a total of 12 sensors each for each replicate/treatment. Sensors will be logged and transmitted wirelessly to a central location, using Decagon's Inc. Em50 transmitters. These sensors allow for continuous 24-7 monitoring of soil moisture.

(c) Leaching rates can be measured if the hydraulic conductivity and the total head gradient across the soil layer below the root zone are known. The leaching flow rate will be calculated using the Darcy equation, and requires total hydraulic head values across two depth increments below the rooting zone, in addition to unsaturated soil hydraulic conductivity values as determined from (a). Nitrate fluxes below the rooting zone will be computed from the Darcy flux calculations associated with soil solution nitrate concentrations across the same depth intervals as the total head measurements.

$$q_{AB} = -K(h)\frac{H_B - H_A}{\Delta z_{A-B}} \qquad (3)$$

where q denotes the Darcy water flux (cm day $^{-1}$), $K(h)$ represent the unsaturated soil hydraulic conductivity, which is a function of the soil matric potential h at the measurement depth. In the Darcy equation, H_A and H_B denote the total water head values at bottom and top of the soil layer below the root zone, respectively, and Δz_{A-B} signifies the thickness of the soil layer between the tensiometers

(d) Rather than using conventional tensiometers to estimate leaching rates, a special deep tensiometer was designed that can be operated across the maximum application range (0- 850 cm), irrespective of installation depth (Fig 3). This was done by installing the pressure transducer at the tensiometer cup, as opposed to conventional tensiometers where the pressure transducer is installed at the soil surface, using a hanging water column. The design was successful tested in the currently–funded ABC project. We believe this new design is critical for application in irrigated systems requiring tensiometer measurements at large depths below the rooting zone, to estimate soil water and nitrate leaching rates.

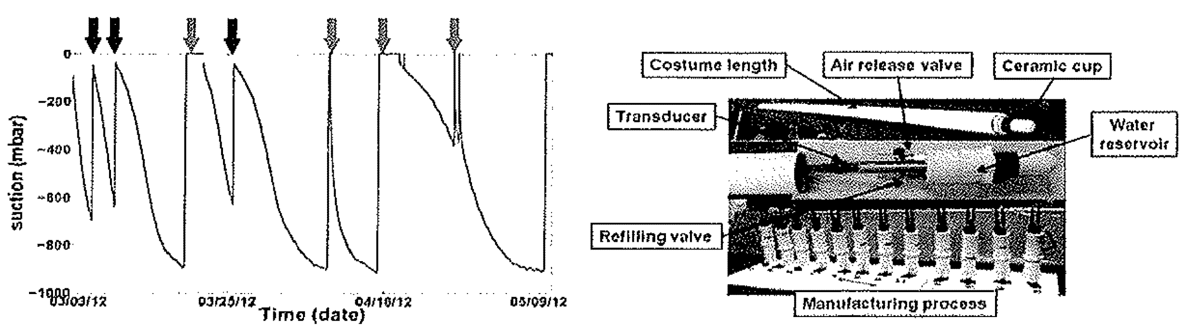


Figure 8a (left panel): Laboratory evaluation of the deep tensiometer during wetting and drying cycles. Red arrows show soil wetting with blue arrows representing times of refilling the tensiometer cup shows the result of laboratory, including times at which the tensiometer was serviced by refilling with water (blue arrows). The component of this new designed tensiometer is presented in **Figure 8b (right panel)**.

Root distribution will be determined using an inverse modeling approach (Vrugt, Hopmans et al., 2001). Briefly, the expected soil water and ion distributions (presume no plant) will be contrasted with measured results (in-situ). The difference between modeled and actual measures will be used to 'map' root activity. This has been previously replicated for almond complete years.

Nutrient Uptake Parameters (Imax, Cmin and Km) have been determined from measured changes in soil ion and water following a fertigation event and by direct measurement of root uptake characteristics in-situ using a depletion technique in which excavated roots are exposed to solutions of varying concentration of nitrate and the depletion of these nutrients over time is measured. Intact roots will be excavated and placed into solution of different concentrations for 30 to 60 minutes of incubation period. The remaining solution will be then analyzed for NO3 and NH_4^+ concentration according to methodology applied by BassiriRad et al. (BassiriRad, Prior et al., 1999).

Leaf, nut, and wood samples will be collected throughout the year and biomass of experimental trees and on a per acre basis will be determined using methodologies optimized in ongoing FREP and Almond and Pistachio research board funded projects. Total tree N accumulation, phenology of uptake and efficiency of N use will be determined. Yield will be determined individually on intensively monitored trees and on a whole orchard basis. Results will be utilized to adjust fertilization regimes and as components of the mass balance required for all other objectives. Sampling strategies will follow those established by Saa-Silva et al (2011)

The tasks and methodologies in this objective are designed to replicate the current activities being conducted with FREP and Almond Board support at Belridge. This replication is essential to 1) provide site specific information for Objectives 2, 4, 5; 2) to extend these approaches to Pistachio; and 3) to validate and demonstrate technologies in different soil types and climates.

Objective 4: Establish proof of concept for use of stable isotopes of $^{15}NO_3^-$ in N tracing under P&F practices.

Traditional ^{15}N labeling techniques are too expensive for field trials of this scale and suffer from considerable uncertainty. A novel alternative approach is proposed for this project. At 'natural abundance' levels, 'fractionation' of ^{15}N (atmospheric N_2 consists of 0.3773% ^{15}N) by physical and biological processes occurs. We predict that NO3- in the vadose zone and water tables in the Central Valley will be diluted with the light ^{15}N abundance found in synthetic fertilizers (Wankel et al. 2009). We will quantify $\delta(^{15}N/^{14}N)$ ($\delta^{15}N$), and $\delta^{18}O$ ($^{18}O/^{16}O$) in nitrate in ground water sources and vadose zone lysimeter samples we gather as well as from fertilizer sources and the organic N fraction of the soils.

The generalized method for calculating the $\delta^{15}N$ (‰) (or $\delta^{18}O$) is:

$$\delta^{15}N = 1000\left(\frac{R_{sample} - R_{std}}{R_{std}}\right) \qquad (4)$$

where R_{sample} is the isotopic ^{15}N abundance on the sample of interest and R_{std} is the abundance of ^{15}N in atmospheric N_2 at R = 0.003773, and $\delta^{15}N$ of atmospheric N_2 = 0.0. Most organic materials have $\delta^{15}N$ of -30.0 to +30.0 and this difference often provides sufficient difference to quantify N-source levels using 'end member mixing models'. Where significant differences emerge, we'll employ binary and tertiary end member models to estimate N-source contribution to potential leachable NO_3^-.

To assess the $\delta^{15}N$ and $\delta^{18}O$ of nitrate (NO_3^-) in ground water and the vadose zone, the isotopic ratios of $^{15}N/^{14}N$ and $^{18}O/^{16}O$ are quantified by converting the solution NO_3^- into nitrous oxide (N_2O) in an oxygen free environment (zero grade N_2). N_2O in the head space then serves as the analyte for continuous flow gas chromatography(GC) isotope ratio mass spectrometry (IRMS). A culture of denitrifying bacteria (*Pseudomonas chlororaphis* and *P. aureofaciens*) is used in this headspace analysis for enzymatic conversion of NO_3^- to N_2O, which follows the reaction pathway shown in equation 1:

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow \tfrac{1}{2}N_2O \qquad (5)$$

Because the bacteria lack N_2O reductase activity, the reaction stops at N_2O, unlike most microbial denitrification reductions that go to completion at N_2. Once the conversion is complete, the zero grade N_2 containing microbially derived N_2O is extracted from the vial and separated from water vapor by an inline nafion membrane drier and from CO_2 with a layered $Mg(ClO_4)_2$/Ascarite trap. N_2O focusing is achieved by trapping the N_2O in a small-volume trap immersed in liquid nitrogen (-196°C). After the N_2O is warmed and released, it is purified by gas chromatography (GC) before being carried by helium to the IRMS via an Agilent GS-Q capillary column (30m x 0.32 mm, 40°C, 1.0 mL min^{-1}). This column separates N_2O from any residual CO_2. The IRMS is a continuous flow isotope-ratio mass spectrometer (CF-IRMS). It has a universal triple collector, consisting of two wide Faraday cups with a narrower center cup for quantifying ratios of 44:45, 44:46 and 45:46 N_2O. The ion beams from these *m/z* values are as follows: $m/z = 44 = N_2O = {}^{14}N^{14}N^{16}O$, $m/z = 45 = N_2O = {}^{14}N^{15}N^{16}O$ or ${}^{14}N^{14}N^{17}O$, and $m/z = 46 = N_2O = {}^{14}N^{14}N^{18}O$. The ${}^{17}O$ contributions to the *m/z* 44 and *m/z* 45 ion beams are accounted for before $\delta^{15}N$ values are reported.

<u>Objective 5</u><u>: Develop and ground validate decision support models (including Hydrus) to assist growers with optimal management of groundwater nitrogen.</u>

In this research study HYDRUS-2D (Šimůnek et al, 2006), one of the most effective modeling approaches, will be field validated, optimized, and refined for the various proposed treatments, and will be used to compare conventional fertigation practices with using groundwater nitrogen. The HYDRUS-2D simulation model allows for specification of root water uptake compensation and active/passive nutrient uptake, reflecting the spatial distribution of water and nutrient availability, and soil water stress effects on transpiration and tree production (Simunek and Hopmans, 2009). This software package can simulate the transient (time-varying) movement of water, salts, and nutrients in soils in multiple spatial dimensions. In addition, the model allows for specification of root water and plant nutrient uptake. The HYDRUS model computes for each specified soil type and irrigation type, the spatial patterns of water content, salt and nitrate concentration between fertigation strategies. Examples of successful application of HYDRUS were presented in Gardenas et al. (2005), Šimunek et al. (2009) and Hanson et al. (2006).

After the specific soil and weather data are available, HYDRUS-2D/3D simulations will be conducted and model data will be compared with field measurements of soil moisture and soil solution nitrate. Soil moisture and weather data (CIMIS) will be used to estimate root water uptake, root zone water and nitrate leaching. After the validation of HYDRUS and satisfactory comparison of model and field experimental data, the HYDRUS model will be coupled with an existing optimization model (MATLAB) to optimize fertigation/irrigation management practices using groundwater nitrate, maximizing water and nutrient use efficiency, while minimizing water (leaching and evaporation) and nitrogen (leaching and denitrification) losses.

This project will optimize the Hydrus model so that it may be used by consultants to guide grower decisions. The information on soil type, root uptake kinetics, and tree productivity will be entered into the program and then a scheduled fertigations/irrigation protocol would be developed. Hydrus is widely used in the global irrigation community and courses on its use are available on-line and in classroom several times a year. The development of an Almond and Pistachio fertigation version of Hydrus will be extended through development of an on-line webinar and update of existing user guidelines.

<u>Objective 6:</u> <u>Demonstrate and proactively extend developed results, technologies and BMP's to growers.</u>

Note: we have a strong commitment from Almond Board, Blue Diamond Growers and Pistachio Board to support, manage and fund the grower extension and demonstration activities associated with this project. This activity will inform the Almond Board/SureHarvest Almond Sustainability Program. It is expected that these sites will become a part of the ILRP monitoring sites and as such will have very high visibility and relevance.

The following outreach and extension events will occur:

-Present the first results and experimental principles and project goals at grower and other stakeholder meetings (possible meetings include FREP, WPHA, Agronomy Society, regional commodity meetings etc.). Prepare educational 'WebCast' video explaining the project. Construct project website.

- In collaboration with Almond Board and Pistachio Research Committee and Farm Advisors from relevant districts, organize 2 or more "field days" to present the new findings to growers, explain how to use the developed models for nutrient decision, illustrate and demonstrate P&F approach and present preliminary outcomes.

- Coordinate web and paper publications in grower and peer reviewed journals. Prepare technical summary for use by commodity boards, water boards and other agencies.

- It is envisioned that outcomes from this project, in coordination with other relevant ongoing projects will be integrated into the Agricultural Sustainability Programs of Almond and Pistachio industries and will be extended to stakeholders utilizing the most relevant and impactful technologies. Please see letters of support from SureHarvest, Almond Board, Pistachio Research Committee and Packard Foundation.

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Scope of Work:

Establish 6 experimental orchards for the following proposed experiment design to test the pump and fertilize (P&F) hypothesis against advanced grower practice (AGP), and a treatment to be determined (TBD) using two nut crops (Pistachio and Almond). Establish experiments in identified hydrogeologic vulnerable areas in the Southern San Joaquin Valley and Tulare Basin. The current proposed experimental orchards consist of:

7. 1 almond orchard under P&F, intensive hydrologic monitoring, N mass balance.
8. 1 almond orchard, AGP and intensive hydrologic monitoring, N mass balance.
9. 1 pistachio orchard, P&F and intensive hydrologic monitoring, N mass balance.
10. 1 pistachio orchard, AGP and intensive hydrologic monitoring, N mass balance.
11. 1 almond orchard, 3 factor design to contrast P&F, AGP and TBD, yields & N mass balance.
12. 1 pistachio orchard, 3 factor design to contrast P&F, AGP and TBD, yields & N mass balance.

For the first 4 sites (1.-4.), we'll establish 4 orchards consisting of two nut crops (pistachio and almond) x two treatments of P&F and AGP (2x2), where intensive monitoring of movement of water and NO_3^- through the vadose zone (root zone) using tensiometers and suction lysimeter arrays, coupled to water use (ETc meteorological towers), intensive ground water (GW) nitrate (NO_3^-) monitoring (GW monitoring wells). The above will be used to capture quantitative information on potentially leachable NO_3^- and first encounter of NO_3^- with shallow aquifer GW. These 4 sites will be used to cross validate the available alternate measures of N loss (lysimeters, soil sampling, soil monitoring devices) and can be used to ground verify modeling efforts to capture N loss (simple nitrogen balance models, Hydrus).

With data from the first 4 orchards, determine natural abundance ^{15}N isotopic ratio on all inputs (fertilizer and irrigation water NO_3^-), for root zone NO_3^- at multiple depths (suction lysimeters), collected soils at multiple depths for water extractable NO_3^- in the rooting zone and for GW samples. Use binary and tertiary isotopic mixing models to determine absorption of N from fertilizer sources versus that from soil mineral-N pools.

For orchards 5. and 6., all 3 proposed treatments will be replicated 4 times in an almond and a pistachio orchard to determine a mass balance for P&F versus AGP and TBD. Included will be the quantification of aboveground net primary production of N (ANPP-N), belowground net primary production of N (BNPP-N). These measures will be used in a nitrogen use efficiency value versus fertilizer N inputs for the 2x3x4 orchards. Soil mineralized N uptake from fertilizer versus native N will be constrained using the isotopic modeling exercises. Yields will be analyzed and reported for the three treatment contrasts.

In year 3 of the project, conduct grower education exercises for use of AGP and P&F practices (and TBD) and help to establish grower adoptable means of monitoring NO_3^--N.

Budget Justification:

Personnel:

A. A Jr. Specialist II or Staff Research Associate is required for the following tasks:

1. Year 1: January 1 – December 31, 2013
    a. Locate appropriate Almond and Pistachio orchards for mass balance and intensive hydrologic monitoring experiments.
    b. Set up experimental design in concert with PIs.
    c. Take comprehensive soil samples from each orchard.
    d. Acquire GIS coordinates for each orchard, generate NRCS SURGGO data bases.
    e. Attain permits for establishing groundwater (GW) monitoring wells and install wells in in intensive monitored almond and pistachio orchards.
    f. Coordinate the purchase of well casing, riser pipe well screens and other materials needed for the GW monitoring wells.
    g. Build tensiometers, suction lysimeters and suction samplers for intensive monitored trees.
    h. Purchase dataloggers, multiplexers and all other electronics hardware needed for intensively monitored trees.
    i. Purchase all electronics hardware necessary for ETc systems.
    j. Work with drilling company and cooperating growers to insure wells are installed correctly and in the correct locations.
    k. Install lysimeters, tensiometers, datalogging equipment and all other electronics, electronics enclosures for intensive monitored trees. Test all equipment to be sure it is functional.
    l. Collect soil samples for soil physical analyses, including soil texture and soil layering, soil water retention and unsaturated hydraulic conductivity.
    m. Purchase and install towers and electrical enclosures to mount surface renewal systems for ETc systems and install towers in each targeted orchard.
    n. Coordinate treatments with cooperating growers to insure N applications are applied in at the correct times and irrigation and are accurately applied. Set up communications for doing this on a regular basis.
    o. Organize harvests for all mass balance experimental treatments and make sure harvested materials are organized and stored properly.

2. Year 2-3: January 1 – June 30, 2015
    a. Continue with Year 1 (tasks l. and m.) and oversee all other field operations outlined in Year 1.
    b. Coordinate sampling GW wells and suction lysimeters, including regular and event related sampling, purchase of storage vials and coordination of NO_3^- field sampling.
    c. Coordinate with all grower cooperators to insure that all treatment conditions are maintained and carried out correctly.
    d. Perform all maintenance for intensively monitored orchards, and set up security systems for more expensive equipment (ETc Towers).
    e. Travel to sites to acquire all data from CR-1000 loggers.
    f. Carry out other tasks as required by consensus decision among PIs and Postdoc.

B. A Postdoctoral Scholar is required for the following tasks:
   1. Year 1: June 1 – December 31, 2013.
      a. Coordinate with Jr. Spec and SRA for collection of water samples from wells and suction lysimeters for ^{15}N analysis.
      b. Aquire fertilizer samples for ^{15}N analyses.
      c. Collect water extractable soil nitrate (NO_3^-) for ^{15}N analyses.
      d. Convert NO_3^- in samples (a. b. and c.) to N_2O and analyze for natural abundance ^{15}N content (atm N_2 as reference).
      e. Establish and interpret database for intensively monitored trees.
      f. Manage and interpret surface renewal data (ETc systems) and resolve any problems with data integrity.
      g. Initiate parameterization of modeling exercises for nitrogen and water balance.
      h. Coordinate data interpretation and writing of biannual report with PIs.
   2. Year 2-3: January 1 – December 31, 2015.
      a. Comprehensive interpretation of ^{15}N data.
      b. Develop binary and tertiary mixing models for $^{15}NO_3^-$ with ANPP-^{15}N and BNPP-^{15}N, as well as similar exercises for hydrologic-^{15}N interpretation and presentation to PIs.
      c. Develop in concert with PIs, ^{15}N isotope experiments and necessary data gathering for 2014 and 2015 growing seasons.
      d. Analyze and synthesize lysimeter, soil moisture and tensiometric data.
      e. Collect all required information (soil properties, ET data, water and nitrogen application data, crop and root information) towards HYDRUS modeling of soil water and soil solution nitrate dynamics and leaching of applied irrigation water and nitrates below the rooting zone towards the groundwater table.
      f. Develop HYDRUS modeling protocols and conduct HYDRUS simulations to compare irrigation and fertilization management practices on water and nitrate leaching.
      g. Develop procedures to expand results of local HYDRUS modeling to the field scale.
      h. Assemble nitrogen mass balance data and perform all statistical analyses for contrasts between AGP and P&F.
      i. Coordinate and write biannual reports with Jr. Spec and all PIs.

C. A GSR (GSR will work for the full duration on this project however funding is requested from CDFA for summer salary only with the remainder of years salary provided through an externally funded fellowship):

1. Year 1-3: July 1 – September 30, 2013-2015.
    a. Work with Jr. Specialist and PostDoc on all relevant tasks including:
        i. Set up experimental design for thesis work in concert with PIs.
        ii. Take soil samples that enable i. from each orchard or assist Jr. Spec on this task.
        iii. Coordinate with Jr. Spec for collection of water samples from wells and suction lysimeters for NO_3^- and for ^{15}N analysis.
        iv. Assist with collection water extractable soil nitrate (NO_3^-) for ^{15}N analyses.
        v. Work with SRA to convert NO_3^- in samples (a. b. and c.) to N_2O and analyze for natural abundance ^{15}N content (atm N_2 as reference).
        vi. Assist Jr. Spec in data collection and maintenance of instrumentation for intensively monitored orchards.
        vii. Work with the Jr. Spec to estabish GIS coordinates for each intensively monitored tree and trees used in the N-balance work. Establish geo-referenced databases to evaluate with orchard variation.
        viii. Assist Jr. Spec with the installation of tensiometers, suction lysimeters and suction samplers for trees in intensively monitored orchards.
        ix. Assist with installation of datalogging equipment and all other electronics, electronics enclosures for intensive monitored trees. Learn how to test all equipment to be sure it is functional and to collect and manage data.
        x. Conduct yield estimations and early season tissue sampling and coordinate with SRA and Postdoc to make sure all data is correctly distributed.
        xi. Help to organize and perform harvests for all mass balance experimental treatments and assist SRA to be sure harvested materials are sufficiently dried, organized and stored properly.

2. Year 2-3: July 1 – September 30, 2014 and 2015
    a. Continue assistance with Year 1 tasks.
    b. Continue with PI directed thesis work related to project goals (eg. mass balance).

D. Staff personnel: Smart lab

1. Staffing in the Smart laboratory (SRA Christine Stockert, ABC and Pistachio request) is required for setting up a NO_3^- conversion system and its maintenance (glass ware, bacterial cultures, gas collection or head space analysis). Managing analytical equipment for all NO_3^- and organic N analyses for the mass balance experiments, supervising database management and assisting with or directly conducting all statistical analyses. Coordination of refrigerators, freezers and all other storage space for sample storage, and taking responsibility for the organization of long-term coordination of sample storage or disposal thereof. Assisting with, or directly ordering of all necessary materials for the Jr. Specialist and Postdoctoral scholar that have to do with laboratory analyses. Hiring of student assistants and keeping records of and reporting their activities. Supervise all student assistants in preparing mass balance samples, weighing and loading into tin capsules for N analysis and keeping track of the samples for the duration of the project. Coordinating with DANR or SIF and other laboratories to insure that sample accuracy is appropriate. Manage the project vehicle, maintenance, records and insure a calendar is maintained for use by multiple teams and personnel. Creating graphics etc. for use in the reporting process and organize the regular meetings of the PIs and other technical staff and participants.

E. Student Assistants are required for the following tasks:

1. Year 1 – Year 3: January 1 2013 – December 31, 2015.
   Under supervision of Jr. Specialist and Postdoctoral Scholar, perform all laboratory exercises associated with analyses of ^{15}N of NO_3^- in soil solution and GW water. Perform all laboratory exercises associated with nitrogen mass balances including tree biomass and soils.

F. Budget Justification: Materials and laboratory analyses.

Costs of materials for GW monitoring wells, suction lysimeters, soil tensiometers and ETc systems are all based on successfully conducted prior projects (budgets are provided). Costs of nitrogen isotope analysis, nitrogen concentration in biomass fractions and NO_3^- analyses are also based on previous projects. Costs of travel and transportation are also derived from accounting for previous efforts in the same regions.