**CDFA Fertilizer Research and Education Program**
**2012 Request for Project Proposals**

**Project Title:** Evaluation of N Uptake and Water Use of Leafy Greens Grown in High-Density 80-inch Bed Plantings and Demonstration of Best Management Practices

**Location:** Commercial Farms in the Salinas Valley
**Duration:** Three years

**Project leaders:**
Richard Smith and Mike Cahn
UCCE Farm Advisors
Monterey County UCCE
1432 Abbott Street
Salinas, CA 93901
(831) 759-7350
rifsmith@ucdavis.edu
mdcahn@ucdavis.edu

**Cooperating Personnel:**
T.K. Hartz
Extension Specialist
Department of Plant Sciences
University of California
1 Shields Ave
Davis, CA 95616
(530) 752-1738
tkhartz@ucdavis.edu

**Supporters**
Monterey County Farm Bureau; Ag Water Coalition

| **CDFA Requested Funding** | Year 1 | Year 2 | Year 3 | Total |
|---|---|---|---|---|
| | 57,576 | 57,851 | 38,207 | 153,634 |

**B. Executive Summary**

Nitrate leaching to groundwater from vegetable production in the Salinas Valley is a continuing and serious problem. The Agricultural Order passed by the Central Coast Regional Water Quality Control Board (CCRWQCB) in March 2012, established nitrogen management requirements with which growers must comply. The following are examples of established regulations for growers in tier 3 (the highest level of regulation): growers must complete an Irrigation and Nutrient Management Plan that must include nutrient budgeting information such as crop nitrogen uptake values, amount of applied nutrient, nutrient balance ratio, and an estimate of nitrate loading to groundwater and reductions achieved. The board considers a nutrient balance ratio of 1.0 (amount applied/amount taken up by the plant) as a milestone, but also the ratio can be interpreted as an indicator of potential nitrate loading to ground water if it is greater than 1.0. Growers are compelled to make improvements in nitrogen use efficiency in vegetable production. Many are on a learning curve to implement best management practices while trying to avoid mistakes that could jeopardize yields, violate contractual agreements with buyers and/or reduce profitability.

Eight-inch wide beds present a particular challenge for managing nitrogen and water. This proposal addresses their specific use for the production of leafy vegetables such as spinach, baby lettuce, spring mix and cilantro. These crops are planted in high-density stands with 24 to32 seedlines across the wide bed top using 2 to 4 million seed per acre. The crops are typically fast maturing, shallow rooted and exclusively sprinkler irrigated. These characteristics create difficulties for achieving high N-use efficiency. A further limitation on N use efficiency are the strict quality standards the growers must meet for these leafy vegetables that can at times compel growers to apply greater quantities of nitrogen fertilizer to "green up" a crop that may have already achieved an acceptable level of yield (Ron Harney, vegetable grower, personal communication). As a result, growers producing leafy green vegetables on high-density, 80-inch wide beds will have difficulty achieving the 1.0 nutrient balance ratio and are "at risk" for complying with guidelines set by the CCRWQCB.

The overall goal of this project is to provide detailed measurements of total N uptake and the N uptake pattern of crops grown on high-density, 80-inch wide beds: spinach, baby lettuce, representative salad mix product (mizuna) and cilantro. Total applied N is critical to crop production, but irrigation efficiency is critical to maintaining nitrate in the shallow root zone of these crops, and therefore this project will also evaluate irrigation management of these crops in comparison with their water requirements. These evaluations will identify potential practices that may reduce nitrate leaching losses.

The information generated in years 1 and 2 will be used to devise and refine algorithms for the CropManage online tool that is designed to assist growers in managing both nitrogen and irrigation management in cool season vegetables. This tool will be used to guide best management decisions in demonstration trials in year three; these trials will be designed to both research the improvements in N use efficiency and to extend information to growers on ways to better manage applied nitrogen and irrigation in this unique production scheme.

**C. Justification**

The Problem: The CCRWQCB regulations have created the need for N uptake data for a variety of crops. In 2009, there were 27,976 acres of spinach, 21,884 acres of spring mix and 4,317 acres of cilantro in California with a combined total value of $453,757,000 (NASS 2010); in addition there are approximately 21,400 acres of baby lettuce (no value estimate available, Mary Zischke, California Leafy Greens Research Board, personal communication). Given the combined acreage and value of these commodities and their importance in the crop rotational schemes of the area, there is a need for research to evaluate their N uptake and irrigation water requirements.

Currently, little information has been published on the N uptake of leafy green vegetables produced in high-density plantings. Smith and Heinrich (2012) conducted preliminary evaluations on the uptake of N by spinach. This data indicated very high rates of nitrogen uptake by the crop in the final 15-20 days prior to harvest (e.g. 7 lbs N/A/day). By contrast, full-sized lettuce takes up in the range of 3-4 lbs N/A/day. A thorough literature search found little information on the N uptake of spinach (Canali et al 2011, Krezel and Kolota 2010, and Werhmann and Scharpf 1986), and no information on any of these crops grown on high-density 80 inch beds. Understanding the quantity of N taken up by these crops is basic to understanding the efficiency of current fertilizer practices and devising improvements in N use efficiency.

Given the tight relationship between applied N and irrigation, there is a need to evaluate ways to reduce nitrate leaching in these shallow rooted crops. The use of fertilizer technology may be able to play a role in maintaining N in the root zone. A typical practice for these high density production systems is to apply robust amounts of N either prior to or at-planting. This applied N is at risk to being lost with the water applied during the germination phase of the crop. There may be possible applications of nitrogen fertilizer technology that can increase nitrogen use efficiency in this scenario. The use of nitrification inhibitors (e.g. Agrotain Plus) or possibly controlled release fertilizers (e.g. Duration 45) may have the potential to increase nitrogen use efficiency and should be evaluated for the early season application.

Much of the potential leaching of nitrate in cool season vegetables is associated with excessive irrigation. We assume that the short-term leafy vegetables grown on high density beds are shallowly rooted and that the inefficiencies associated with applying water using overhead sprinklers could lead to substantial nitrate movement below the rooting zone. A survey of the quantity of water applied during the crop production cycle needs to be conducted to better understand typical water application patterns relative to crop demand (crop ET). There are critical periods in the irrigation schedule of these crops such as during germination when large volumes of water are applied to establish a uniform stand and during fertigation events when a portion of the applied N fertilizer may end up in the furrow and therefore result in no use to the current crop or runoff of the field. In addition, there are subtleties of the sprinkler system such as excess water applied to furrows where the pipe is located due to drainage during the beginning and end of the irrigation cycle. This is important because total N application rates may be adjusted upwards to crops like spinach to avoid having the spinach next to the sprinkler line

furrow from turning yellow because of excessive leaching on light soils. Water use of leafy vegetables grown on high-density beds has not been well documented on the Central Coast to determine if growers apply significantly more water than crop ET. This project would also compare irrigation scheduling with crop water requirements of high-density production of leafy vegetables and identify potential irrigation practices that may reduce nitrate leaching losses. Practices such as applying less volume of water more often and using weather based approaches to irrigation scheduling could reduce potential leaching. Also, practices that can maximize sprinkler irrigation efficiency such as replacing worn nozzles, optimizing pressure, and replacing leaking gaskets in pipes can prevent excessive drainage.

All of the information generated by this project in years 1 and 2 will be used to refine the algorithms in CropManage, an online tool that is designed to assist growers in managing both nitrogen and irrigation management in cool season vegetables. In collaboration with ANR communication services, and funding from CDFA/FREP, Cahn et al. (2011) developed a web-based irrigation scheduling and nitrogen management tool for romaine and head lettuce, known as CropManage (https://ucanr.org/cropmanage). CropManage is a database-driven application that assists growers and farm managers in determining watering schedules on a field-by-field basis. Ranch/farm data, such as field names, associated soil types and acreage, are preloaded so that the information is available on demand for estimating irrigation schedules. The software automates all steps required to calculate crop water requirements, including retrieving the CIMIS ETo and precipitation data from the closest weather station, estimating the crop coefficient, and determining the appropriate irrigation time and interval based on soil type and models of crop development. The web application also helps growers track irrigation schedules on multiple fields and allows users from the same farming operations to view and share their data. CropManage was designed to be as intuitive to use as possible for growers and farm managers who have many responsibilities to carry out in their daily farming operations. Users can quickly see summaries of water use and irrigation recommendations of each of their planted fields, as well as append summaries with new water use records. In addition to irrigation capabilities, CropManage includes a fertilizer nitrogen module for lettuce which estimates the appropriate N fertilizer application from current soil nitrate test data (Hartz et al. 2000) and estimated crop N uptake and soil mineralization rates. Information on the crop nitrogen uptake pattern, crop canopy measurements and ET estimates, and rooting depth will improve estimates of nitrogen and water requirements for these crops and expand the usefulness of CropManage for vegetable producers.

CDFA/FREP goals: This proposal addresses FREP goals by providing reliable information on total N uptake and the pattern of N uptake by key crops in the coastal production district. The project addresses the following FREP goals: 1 Crop Nutrient Requirements; 2 Fertilization Practices; Fertilizer and Water Interactions; and 7 Education. By providing information on the uptake pattern of N by these crops, and the rooting pattern, it will provide information to help better time fertilizer applications and help to better understand where the active zone of N uptake in the soil is located. These aspects of N management are linked to irrigation management. Measurements of crop

canopy development will provide information on crop coefficients and will provide the tools to help growers to better manage applied irrigation water.

Impacts: Given the growing use of high-density 80-inch wide beds for leafy green production, improvements in the understanding of fertilization and irrigation practices can significantly impact water quality concerns. These crops are high value and have significant economic impact in the coastal production district. The use of this production system is also being adopted by other crops (e.g. green onions, rapini, etc.) and the information gained on N and water management can be of use for these crops as well.

Long-term solution: This project will provide key information that will allow growers to continue to make progress towards managing applied N more efficiently while reducing nitrate loading to ground and surface waters. The application of the data generated by this project to the CropManage online tool is innovative and may provide an avenue for future N management research by integrating N and water management and refining the CropManage software.

Related Research: There have been a number of studies that have examined irrigation and nutrient management in full maturity lettuce. Smith et al (2009) demonstrated that the first sidedress applications to lettuce could be reduced based on nitrogen uptake data. However, high-density 80-inch bed culture for leafy vegetables has not been extensively studied and this proposed research will begin to fill in a significant data gap.

Contribution to knowledge base: This project would provide practical data on nitrogen uptake and water use of leafy vegetables grown on high-density 80-nch bed culture. The use of the CropManage online tool will help advance our ability to integrate the influences of crop root development, crop N uptake pattern, N application amount and timing, and the impact of water management. Integration of these influences will help growers to make improvements in nitrogen use efficiency.

Grower use: Growers on the Central Coast are under intense pressure to improve nitrogen use efficiency to all crops. Given the pressures from municipalities to provide drinking water that meets the water quality standard of 10 ppm $NO_3$-N, it is critical the growers do their part to improve nitrogen use efficiency as much as possible. Having current and reliable data on total N uptake, N uptake pattern, rooting depth and the impact of irrigation on nitrate loss is fundamental to achieving this goal.

**D. Objectives**

1. Document the quantity and pattern of N uptake pattern over the life cycle of spinach, baby lettuce, a representative salad mix vegetable (e.g. mizuna) and cilantro
2. Evaluate quantities of irrigation water applied to these crops over the course of the growth cycle
3. Evaluate the rooting depth of the crops over the growing season
4. Evaluate fertilizer additives such as urease and nitrification inhibitors with pre/at-planting fertilizer applications to improve N use efficiency

5. Utilize the information gained on nitrogen uptake, water needs and rooting depth in the third year to refine the algorithms in the CropManage web based tool and conduct a demonstration evaluation in the third year of the project

**E. Workplan and Methods**

A survey of five well-managed, high-yielding fields of spinach, baby lettuce, a representative salad mix (mizuna) and cilantro fields in Monterey County will be conducted. Fields will be selected that have typical production practices for this region. Fields will be selected that encompass the range of microclimatic factors close to the coast and inland. These evaluations will be conducted on 20 commercial fields (five of each commodity) in 2013 and 2014 production seasons (40 total fields). A soil sample for each field will be conducted that will include pH, EC, Olsen P, exchangeable K and organic matter analyses. An analysis of the salinity and nitrate content of the irrigation water will also be conducted. Crop biomass and biomass N will be measured at harvest for all five fields for each commodity each year to provide an estimate of N uptake by these crops. Biomass samples and soil mineral nitrogen will be collected 3 times during the production cycle in two of the above mentioned fields of each commodity in each year to measure the N uptake pattern. Two fields of organic baby lettuce will be included in the survey each year. Biomass samples will be collected from a 1.0 $m^2$ area from 4 replicate areas per field. At harvest, total biomass and commercially harvested biomass and biomass N will both be measured. Fertilizer application rates and timing in each field will also be documented. Biomass samples at harvest will also be analyzed for phosphorus and potassium to provide information on the uptake of these key nutrients.

Rooting density of the crops will be characterized at weekly intervals in three locations in the field during the crop growth cycle until harvest in one field of each commodity each year. At harvest, pits will be dug near harvest to expose a cross-section of the bed and map out the final the distribution of roots. These data will be used to quantify the effective rooting zone of these crops during the various stages of development and will provide information that will improve the estimates of nitrogen and water uptake by the CropManage program.

Flow meters will be installed in the two fields of each commodity that are being evaluated each week to monitor the volume of water applied from crop establishment to harvest. The flow meters will be connected to data loggers to record the length and frequency of irrigations. Infra-red canopy photos will be taken every week to develop crop coefficients for estimating crop ET. Soil moisture sensors will also be installed to monitor changes in soil moisture storage. These data will provide an estimate of the volume of irrigation water drainage below the root zone. An evaluation of the effect of extra water applied to the furrow where the sprinkler line is located due to leakage will be made by collecting soil samples for nitrate analysis. In addition, estimates of N loss due to runoff during N application through sprinklers will be made.

Two fertilizer trials will be conducted each year on baby lettuce to evaluate pre/at planting fertilizer applications with fertilizer additives including urease and nitrification inhibitors (Agrotain Plus) as well as controlled release fertilizer (Agrium D45) in

comparison with ammonium fertilizers to determine if these products can improve N use efficiency of early season fertilizer applications.

Collected data on crop water use, N uptake, and rooting depth of high density plantings of leafy greens will be summarized in algorithms that will be incorporated into the CropManage program. We will conduct 2 demonstration trials of best management practices (BMP) guided by the CropManage water and N fertilizer recommendations during the 3rd year of the project.

**Workplan Year 1**

Task 1: Conduct N, irrigation and root evaluations of 20 spinach, baby lettuce, representative spring mix (Mizuna) and cilantro fields 2013

Sub-task 1.1 Conduct N uptake pattern and total N uptake evaluations

1. Select 5 high yielding fields each of spinach, baby lettuce, representative spring mix (Mizuna) and cilantro from diverse areas of Monterey County (coastal to interior and diverse soil types)
2. Conduct biomass, biomass N and soil nitrate evaluations at harvest for each field and multiple biomass evaluations during the grown cycle on 2 field from each crop type
3. The at-harvest evaluation will include analysis of phosphorus and potassium content of the crops

Sub-task 1.2 Conduct crop canopy evaluations and irrigation application evaluations

1. Install flow meters in above mentioned fields
2. Take infra-red canopy photos of crops every week on two fields of each commodity
3. Install and maintain soil moisture monitoring sensors
4. Furrow bottom efficiency evaluations and N loss during fertigation

Sub-task 1.3 Conduct rooting depth evaluations

1. Conduct rooting depth measurements each week during the crop cycle for each commodity
2. Conduct evaluation of total root system of one field of each commodity near harvest

Sub-task 1.4 Conduct two pre or at-planting fertilizer trials of baby lettuce

1. Trials will consist of evaluations of a nitrification inhibitor (e.g. Arotain Plus applied with UN32) and a controlled release fertilizer (e.g. Duration 45) in comparison with standard pre/at-planting fertilizer practices. Given the general use of sprinklers to apply the second fertilizer application, no modification of the second fertilizer application will be made.

Sub-task 1.5 Analyze all data and prepare mid-term report to FREP

Sub-task 1.6 Reports and extension

1. Provide mid-term report to FREP
2. Report preliminary results to the annual Irrigation and Nutrient Management Meeting and UCCE newsletters

**Workplan Year 2**

Task 1: Conduct N, irrigation and root evaluations of 20 spinach, baby lettuce, representative spring mix (Mizuna) and cilantro fields 2014

Sub-task 2.1 Conduct N uptake pattern and total N uptake evaluations

1. Select 5 high yielding fields each of spinach, baby lettuce, representative spring mix (Mizuna) and cilantro from diverse areas of Monterey County (coastal to interior and diverse soil types)
2. Conduct biomass, biomass N and soil nitrate evaluations at harvest for each field and multiple biomass evaluations during the grown cycle on 2 field from each crop type
3. The at-harvest evaluation will include analysis of phosphorus and potassium content of the crops

Sub-task 2.2 Conduct crop canopy evaluations and irrigation application evaluations

1. Install flow meters in above mentioned fields
2. Take infra-red canopy photos of crops every week on two fields of each commodity
3. Install and maintain soil moisture monitoring sensors
4. Furrow bottom efficiency evaluations and N loss during fertigation

Sub-task 2.3 Conduct rooting depth evaluations

1. Conduct rooting depth measurements each week early in the crop cycle and bi-monthly during the latter half of the crop cycle of one field of each commodity
2. Conduct evaluation of total root system of one field of each commodity near harvest

Sub-task 2.4 Conduct two pre or at-planting fertilizer trials of baby lettuce

1. Trials will consist of evaluations of a nitrification inhibitor (e.g. Arotain Plus applied with UN32) and a controlled release fertilizer (e.g. Duration 45) in comparison with standard pre/at-planting fertilizer practices. Given the general use of sprinklers to apply the second fertilizer application, no modification of the second fertilizer application will be made.

Sub-task 2.5 Analyze all data and prepare final-term report to FREP

Sub-task 2.6 Reports and extension

1. Final report to FREP
2. Provide report of final results to the annual Irrigation and Nutrient Management Meeting and annual FREP Conference
3. Publish results in UCCE newsletters, trade journals and prepare peer reviewed manuscript for submission to a scientific journal

**Workplan Year 3**

Task 1: Conduct a two demonstration trials utilizing the information developed in years 1&2 to refine the CropManage web based model. The refined information will be used to guide decisions on the best management practices to be utilized in the production of baby lettuce and spinach, 2015.

Sub-task 3.1 Conduct best management practice demonstration on lettuce and spinach

1. Refine the algorithms in the CropManage model based on the information on crop N uptake pattern and amount, crop Et and rooting depth developed in years 1 and 2 of the project
2. Coordinate with a commercial grower to conduct a demonstration trials on one crop of lettuce and one of spinach
3. Manage the BMP plots using the CropManage program and compare with the growers standard practice
4. Evaluate the difference in N and water use and nitrate leaching in the two management schemes

Sub-task 3.2 Analyze all data and prepare final-term report to FREP

Sub-task 3.3 Reports and extension

1. Final report to FREP
2. Provide report of final results to the annual Irrigation and Nutrient Management Meeting and annual FREP Conference
3. Publish results in UCCE newsletters, trade journals and prepare peer reviewed manuscript for submission to a scientific journal

**F. Project Management, Evaluation, and Outreach**

Management: Richard Smith and Michael Cahn will be responsible for conducting the field evaluations on N uptake and crop water use. Tim Hartz will provide technical input to these evaluations.

Evaluation: The project will be conducted over two years and will complete 40 evaluations of spinach, baby lettuce, representative spring mix (mizuna) and cilantro. In the third year, two demonstration trials will be conducted comparing BMP's provided by the CropManage web based program and the growers standard practice.

Outreach: The results of the evaluations will be reported at the annual Irrigation and Nutrient Management meeting in February in Salinas in February of 2014 and 2015. Results will be published in *Monterey County Crop Notes* and the *Central Coast Agricultural Highlights* newsletters (cover Monterey, Santa Cruz, San Benito, Santa Clara, San Luis Obispo and Santa Barbara counties) in 2014 and 2015, trade magazines (e.g. *Ag Alert* and *Vegetables West*) and a scientific journal to provide a peer reviewed reference of the findings at the conclusion of the project.

**Literature Cited**

Cahn, M., M.J. English, T. Hartz. 2011. Irrigation and nitrogen management web-based software for lettuce production. 19th annual CDFA Fertilizer Research and Education Program Conference Proceedings. Tulare, CA. pp. 19-21.

Canali, S., F.Montemurro, F. Tittarelli, and O. Masetti. 2011. Is it possible to reduce nitrogen fertilization in processing spinach. Journal of Plant Nutrition 34:534-546.

Krezel, J. and E. Kolota. 2010. The effect of nitrogen fertilization on yielding and biological value of spinach grown for autumn harvest. Acta Scientiarum Polonorum-Hortorum Cultus 9(3): 183-190

Hartz, T.K., W.E. Bendixen, and L. Wierdsma. 2000. The value of presidedress soil nitrate testing as a nitrogen management tool in irrigated vegetable production. HortSci. 35(4):651-656.

NASS USDA. 2011. California County Agricultural Commissioner's Data for 2010. http://www.nass.usda.gov/Statistics_by_State/California/Publications/AgComm/Detail/index.asp

Smith, R., M. Cahn, T. Hartz, M. Silva Ruiz. 2009. Growth rate of lettuce: implications for nitrogen fertilization. In: program and abstracts ASHS Annual Conference 25-28 July 2009, St. Louis MO. HortScience 44(4), 1023.

Smith, R.F. and A. Heinrich. 2012. Nitrogen uptake by spinach: results of the 2011 evaluations. 2012. *Monterey County Crop Notes*, March/April.

Werhmann, J. and H.C. Scharpf. 1986. The Nmin method – an aid to integrating various objectives of nitrogen fertilization. Journal of Plant Nutrition and Soil Science 149: 428-440.

## G. Budget

The budget exceeds the $50,000 limit in years 1 & 2. Costs have increased significantly for salaries, benefits and the UCANR Analytical Lab. We included costs for phosphorus and potassium analyses in those years, and if the exceedance is a problem, we can remove those analyses from the budget to meet the spending limit. **(BUDGET APPROVED BY CDFA PROGRAM-SEE ATTACHED TASK BUDGET)**

## H. Deliverables

| Deliverables | Due Date |
|---|---|
| **Interim Report w/Invoice** For services 1/1/13--6/30/13 | 7/31/2013 |
| **Annual Report w/Invoice** For services 7/1/13--12/31/13 | 1/31/2014 |
| **Interim Report w/Invoice** For Services 1/1/14--6/30/14 | 7/31/2014 |
| **Second Annual Report w/Invoice** For services 7/1/14--12/31/14 | 1/31/2015 |
| **Interim Report w/Invoice** For Services 1/1/15--6/30/15 | 7/31/2015 |
| **Final Report w/Invoice** For Services 7/1/15--12/31/15 | 1/31/2016 |