Project title: Determining the Fertilizer Value of Ambient Nitrogen in Irrigation Water

Project location: Salinas Valley

Project duration: 3 years

Project leaders:

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Supporters:

Monterey Regional Water Pollution Control Agency: primary agency responsible for providing recycled water for the Castroville Seawater Intrusion Project (CSIP).

Monterey County Water Resource Agency: principal agency for managing ground and surface water supplies in the Salinas Valley, including the Nacimiento and San Antonio Reservoirs, and Salinas River; MCWRA manages the Salinas Valley Water Project, and jointly manages CSIP with MRWPCA.

CDFA Funding:

Year 1	Year 2	Year 3	Total
$ 87555	$ 106,570	$ 86,411	$280,536

B. Executive summary:

Irrigation water from many wells on the central coast contains a significant amount of nitrate-nitrogen (NO_3-N); recycled water from the Monterey Regional Water Pollution Control Agency, the sole water source for approximately 12,000 acres of prime Monterey County farmland, is high in both NO_3-N and NH_4-N. Growers historically have been reluctant to modify their N fertilization practices on the basis of irrigation water N content because it is unclear how one can reliably calculate the 'fertilizer value' of this N. This issue has taken on added significance with the adoption of the new 'Ag Order' by the Central Coast Region Water Quality Control Board during March, 2012.

The revised Ag Order requires growers to report the total amount of nitrogen applied to crop land, including N contained in irrigation water. It is also unclear what distinction, if any, the Board will make between fertilizer and water sources of N, but it is clear that the Board expects growers to modify their N management practices based on the N content of irrigation water applied to their crops. Unfortunately, a limited body of research documents the efficiency of crop uptake of N from irrigation water, upon which to base an estimate of 'fertilizer value' under normal irrigation and N management practices. This project will develop information and guidelines for utilizing ambient N in irrigation water for lettuce, the primary crop in this region. A total of 4 replicated field trials will be conducted in the Salinas Valley from 2013-14. Two trials will focus on determining the efficiency of lettuce to recover N from irrigation water, as affected by concentration and irrigation efficiency. The remaining trials will examine the practical contribution of irrigation water N to crop fertility under a range of typical irrigation and N fertigation regimes. This project will have a strong outreach component, including newsletter and trade journal articles, oral presentations, and online resources. We will add an algorithm for calculating the fertilizer value of NO_3/NH_4 in irrigation water to the online irrigation and N management tool, CropManage, as well as a downloadable spreadsheet tool for making similar calculations.

C. Justification:

Vegetable production on the Central Coast faces an unprecedented challenge from environmental water quality regulation. While a number of provisions of the recently updated 'Ag Order' adopted by the Central Coast Region Water Quality Control Board present issues for growers, the provisions regarding N content of irrigation water are particularly problematic. Growers in enforcement tiers 2 and 3 (which will include most vegetable and strawberry growers) will be required to report annual N application on their ranches. N content of irrigation water is explicitly included in this reporting requirement.

Many growers have no choice but to use irrigation water of high nitrogen content. Surveys by the Monterey County Water Resource Agency have suggested that regionally more than a third of wells used for irrigation may exceed the 10 PPM NO_3-N federal drinking water standard. In these high NO_3-N wells concentrations above 20 PPM are common, with some wells exceeding 40 PPM. Additionally, recycled water from the Monterey Regional Water Pollution Control Agency (MRWPCA) that is delivered to growers in the Blanco District of Monterey County averages approximately 40 PPM total N (10-15 PPM NO_3-N, and the remainder in the form NH_4-N; for recycled water quality information see http://www.mrwpca.org/recycling/water_quality.php). This water is the sole source of irrigation for approximately 12,000 acres of prime farmland (Platts et al., 2004). Recycled water provided by the Pajaro Valley Water Management Agency is also used for irrigation of approximately 6,000 acres of vegetables and berries in the Pajaro Basin. For growers using high nitrate wells, or receiving water from the MRWPCA, the N content of irrigation water constitutes a substantial portion of the overall ranch N budget; an acre foot of water at 40 PPM N contains > 100 lb N.

While the Ag Order is not explicit in describing how the Board will view environmental N loading from irrigation water N *vs.* that from mineral fertilizer, the obvious implication is that growers should factor irrigation water N into their fertility management program. Extension publications around the country suggest that the 'fertilizer value' of irrigation water can be calculated based on NO_3-N concentration, water volume applied and irrigation efficiency; for examples see Hopkins et al. (2007) or Bauder et al. (2011). While that idea is sound in the abstract, there is a paucity of field data to document that crop utilization of irrigation water N is as efficient as these estimates suggest. It is clear that vegetable crops can utilize mineral N at relatively low concentration in water; Vavrina et al. (1998) found that as little as 20 PPM N in irrigation water was adequate to produce greenhouse tomato transplants (although higher concentration was required to maximize transplant growth rate). What is not clear is the degree to which N in irrigation water can substitute for fertilizer N under typical field fertilization and irrigation regimes.

Central coast vegetable growers have several concerns with a simplistic concentration × volume approach to estimating the fertilizer value of ambient N in irrigation water. High N water sources, including both groundwater and recycled water, often also have significant levels of sodium and chloride. It is unclear what portion of the N in the irrigation water applied to leach salts should be credited as N value to the crop since that water would percolate below the root zone. Similarly, variation in irrigation uniformity in a field also affects the portion of N in irrigation water that can be credited as N value to a crop since some areas of a field would have more deep percolation than other areas. Crops such as lettuce and broccoli with characteristically different rooting depths may also have varying abilities to utilize ambient N contained in applied irrigation water. We hypothesize that only the portion of water equal to the consumptive use of the crop (crop evapotranspiration) would contribute to plant N uptake. A second concern is that relatively low N concentrations in irrigation water may not significantly contribute to crop N uptake under normal production conditions. In fertilized vegetable root zones, soil water NO_3-N concentration is typically 50-150 PPM. In growers' minds it is unclear if the addition of water with much lower N concentration represents a significant net benefit to crop N nutrition.

An additional concern about the fertilizer N value of irrigation water is specific to MRWPCA recycled water used to annually irrigate more than 12,000 acres of vegetables and berries grown on the central coast. A major portion of the N in this water is in the NH_4^+ form. Because of NH_4^+ is a cation it would be less likely to leach than NO_3^-, and therefore may have more fertilizer value than NO_3-N.

In summary, Central coast growers have three basic questions concerning the fertilizer value of N in irrigation water:

1. Can crops effectively utilize irrigation water nitrogen at relatively low concentrations?
2. To what degree do factors such as irrigation efficiency, crop species, and leaching fraction affect crop recovery of irrigation water N?
3. Does NH_4^+ in irrigation water have more fertilizer N value than NO_3^-?

This project proposes to develop data to address these questions.

D. Objectives:

1) Document broccoli and lettuce N uptake and N recovery efficiency (NRE) of irrigation water N over the range of 10-40 PPM, and at high and low irrigation efficiencies.

2) Determine the contribution of irrigation water N to broccoli and lettuce N fertility under a range of typical drip irrigation and fertigation practices.

E. Work Plans and Methods:

Year 1 field trials: Two field trials (a spring and a summer crop) will be conducted on the USDA Spence Road research facility near Salinas in 2013 to address objective 1. The irrigation water available at this facility contains approximately 2 PPM NO_3-N. Lettuce growth and N uptake will be compared across a range of treatments simulating different levels of N in irrigation water, plus fertilized and unfertilized controls. Nitrogen treatments will include:

1. Unfertilized control (approximately 2 PPM NO_3-N in the irrigation water)
2. fertilized control (seasonal total of 150 lb N applied in weekly fertigations)
3. 10 PPM NO_3-N in irrigation water
4. 20 PPM NO_3-N in irrigation water
5. 40 PPM NO_3-N in irrigation water
6. 40 PPM mineral N (10 PPM NO_3-N and 30 PPM NH_4-N in irrigation water, simulating MRWPCA recycled water)

To observe the interaction of irrigation efficiency and NRE, each of these treatments will be evaluated at two levels of drip irrigation [110% and 150% of crop ET as estimated by canopy cover using the equation of Gallardo et al. (1996)]. The experimental design for each trial will be randomized complete block, with four replications. Each of the 48 individual plots will be four 40-inch wide beds by 40 ft, with all data collected from the middle beds. Crisphead lettuce will be seeded in 2 rows per bed, and germinated and established with sprinklers. After thinning, the crop will be irrigated with water of vary levels of ambient N (treatments 1-6) using drip tape.

Before planting, fields will be sprinkler irrigated to leach residual NO_3-N so that each trial will be conducted with low background soil N availability (< 10 ppm soil NO_3-N); the soil at the site (a well drained Chualar sandy loam) can be relatively easily managed in this regard. Water-powered proportional injectors will be used to enrich all drip applied water to the target concentrations of treatments 1-6. Injected NO_3-N will be a blend of $Ca(NO_3)_2$ and $NaNO_3$ to maintain the cation balance in the water. Injected NH_4-N will be in the form of NH_4SO_4. An emitter inserted into the drip lines will collect a composite water sample from each N treatment to confirm that target N concentrations were attained during each irrigation. The fertilized control will receive N in the form of AN-20.

Data Collection: Canopy cover of the treatments will be estimated using a near-infra-red digital camera at weekly intervals. Flow meters will be used to determine the volume of water applied to the 110% and 150% ET treatments. In both trials soil samples will be collected at 0-1 ft, 1-2ft and 2-3 ft depth prior to the initiation of N treatments, and at harvest; field-moist samples will be extracted in 2 N KCl and analyzed for NH_4-N and NO_3-N to document the pattern of mineral N movement. All plots will be harvested when the fertilized control treatment reaches commercial maturity. Plant above-ground fresh and dry weight, and biomass N content, will be determined.

Year 2 field trials: In 2014, 3 additional trials will be conducted at the USDA facility to address objectives 1 and 2.

Lettuce trials Two trials (spring and summer) will be conducted to address objective 2. Replicated plots of four fertigation treatments (a seasonal total of 0, 50, 100 or 150 lb N from AN-20) will be grown, with each N fertigation level produced with three irrigation water N concentrations:

- non-enriched water (native 2 PPM NO_3-N)
- water enriched to 20 PPM NO_3-N
- water enriched to 40 PPM N (10 PPM NO_3-N and 30 PPM NH_4-N, similar to MRWPCA water)

These 12 treatment combinations will be produced with drip irrigation applied at 110% of calculated crop ET, determined as previously described. Three additional treatments will be included to test the effects of a higher leaching fraction; the following treatment combinations will be irrigated at 150% of crop ET:

- seasonal fertigation of 100 lb N/acre, non-enriched water
- seasonal fertigation of 100 lb N/acre, water enriched to 20 PPM NO_3-N
- seasonal fertigation of 100 lb N/acre, water enriched to 40 PPM N (10 PPM NO_3-N and 30 PPM NH_4-N, similar to MRWPCA recycled water)

A total of 15 treatment combinations will be arranged in a randomized complete block experimental design. There will be four replicate plots of each treatment combination, with individual plots 4 beds wide by 40 ft long. As in 2013, the fields will be sprinkler irrigated to leach residual NO_3-N so that each trial will be conducted with low background N availability.

Broccoli trial A third field trial will be conducted in a different field at the USDA facility during the summer to address objective 1 for a crop with a deeper rooting depth than lettuce. Broccoli growth and N uptake will be compared across a range of treatments simulating different levels of N in irrigation water, plus fertilized and unfertilized controls. The nitrogen water treatments 1-6 used for the lettuce trials in year 1 will be adapted to broccoli:

1. Unfertilized control (approximately 2 PPM NO_3-N in the irrigation water)
2. fertilized control (seasonal total of 225 lb N applied in weekly fertigations)
3. 10 PPM NO_3-N in irrigation water
4. 20 PPM NO_3-N in irrigation water
5. 40 PPM NO_3-N in irrigation water
6. 40 PPM mineral N (10 PPM NO_3-N and 30 PPM NH_4-N in irrigation water, simulating MRWPCA recycled water)

Similar to the lettuce trials, each of these treatments will be evaluated at two levels of applied water (110% and 150% of Crop ET) to evaluate the interaction of irrigation efficiency and NRE. The experimental design for each trial will be randomized complete block, with four replications. Each of the 48 individual plots will be four 40-inch wide beds by 40 ft, with all data collected from the middle beds. Broccoli will be seeded in 2 rows per bed, and germinated and established with sprinklers. Procedures for pre-leaching residual soil NO_3-N, simulating varying levels of ambient N in irrigation water, and estimating crop ET, will be the same as described for the year 1 trials.

Data collection Data collected from each trial will include plant above-ground fresh and dry biomass, and biomass N content. Plant N status will be determined through wrapper leaf sampling at the rosette stage and at harvest. At harvest the marketable yield (percent of plants that are marketable, and mean trimmed weight) will be recorded. Soil sampling will be conducted as described for the 2013 trials. Canopy cover of the treatments will be estimated using a near-infra-red digital camera at weekly intervals. Flow meters will be used to determine the volume of water applied to the 110% and 150% ET treatments.

Year 3 field trials: In 2015, one field trial will be conducted at the USDA facility to address objective 2 for broccoli. An additional trial will be conducted at the USDA facility to redo any prior field trials that were unsuccessful due to production conditions (disease, insect pests, weather).

Broccoli trial A field trial will be conducted in the summer will be conducted to address objective 2. Replicated plots of four fertigation treatments (a seasonal total of 0, 75, 150 or 225 lb N from AN-20) will be grown, with each N fertigation level produced with three irrigation water N concentrations:

- non-enriched water (native 2 PPM NO_3-N)
- water enriched to 20 PPM NO_3-N
- water enriched to 40 PPM N (10 PPM NO_3-N and 30 PPM NH_4-N, similar to MRWPCA water)

These 12 treatment combinations will be produced with drip irrigation applied at 110% of calculated crop ET, determined as previously described. Three additional treatments will be included to test the effects of a higher leaching fraction; the following treatment combinations will be irrigated at 150% of crop ET:

- seasonal fertigation of 150 lb N/acre, non-enriched water
- seasonal fertigation of 150 lb N/acre, water enriched to 20 PPM NO_3-N
- seasonal fertigation of 150 lb N/acre, water enriched to 40 PPM N (10 PPM NO_3-N and 30 PPM NH_4-N, similar to MRWPCA recycled water)

A total of 15 treatment combinations will be arranged in a randomized complete block experimental design. There will be four replicate plots of each treatment combination, with individual plots 4 beds wide by 40 ft long. As in 2013 and 2014, the fields will be sprinkler irrigated to leach residual NO_3-N so that each trial will be conducted with low background N availability

Data analysis The structure of the field trials for objective 1 will allow a robust evaluation of the crop recovery of N from irrigation water. N recovery from irrigation water N will be calculated by subtracting the crop biomass N of the unfertilized control from the biomass N of each treatment receiving N in irrigation water. Nitrogen recovery efficiency (NRE) of each irrigation N × irrigation volume combination will be calculated by comparing the uptake of irrigation water N to the total amount of N applied to the crop through the irrigation water:

$$NRE\ (\%) = [(BiomassN_x - BiomassN_0)/waterN_x] \times 100$$

where $BiomassN_x$ is the N (lb/acre) in the crop biomass of treatment x, $BiomassN_0$ is the N in the biomass of the background water treatment (0 N added), and $waterN_x$ is the total N applied to the crop through the irrigation water treatment x.

The effect of N form in irrigation water will be evaluated using orthogonal contrasts to compare the performance of the 40 PPM NO_3-N treatments and the 40 PPM mixed N form (NH_4^+ and NO_3^-) treatments. Field trials under objective 2 will allow the direct comparison of the efficiency of irrigation water N and an industry standard N management practice (periodic N fertigation).

Linear and quadratic response models will be used to relate irrigation water N concentration, crop ET, and irrigation efficiency to NRE. From these analyses an algorithm will be developed to estimate the fertilizer value of irrigation water N. The algorithm will be utilized on the 'CropManage' web-based irrigation and N management tool currently being developed by Cahn et al (2011) to provide guidance to growers (ucanr.org/cropmanage).

Note: While we recognize that the educational value of these trials might be greater if conducted on commercial farms, we do not believe that it is practical to do so. There would be significant logistical challenges to producing replicated plots of the varying combinations of fertigation, irrigation level and water N concentration, and our requirements would place a significant burden on cooperating growers. Furthermore, it would be unlikely that we would find fields with both irrigation water with low nitrate concentrations and the required low background soil N fertility.

Workplan year 1:

Task 1. Conduct 2 field trials at the USDA Spence research farm.

Subtask 1. Identify field sites, leach fields as required to reduce residual soil NO_3-N.

Subtask 2. Establish lettuce crops, install irrigation/ fertigation systems, and conduct trials.

Task 2. Analyze data, prepare reports for FREP and presentation for Salinas outreach meeting.

Subtask 1. Analyze and organize field data.

Subtask 2. Prepare and submit interim report and interpretive summary to FREP.
Subtask 3. Prepare presentation for delivery at the Salinas outreach meeting in winter, 2014.

Workplan year 2:
Task 1. Conduct 3 field trials (2 lettuce and 1 broccoli trial) at the USDA Spence research farm.

Subtask 1. Identify field sites, leach fields as required to reduce residual soil NO_3-N.
Subtask 2. Establish lettuce/broccoli crops, install irrigation/ fertigation systems, and conduct trials.

Task 2. Analyze data, prepare reports for FREP and presentation for Salinas outreach meeting.

Subtask 1. Analyze and organize field data.
Subtask 2. Prepare and submit interim report and interpretive summary to FREP.
Subtask 3. Prepare presentation for delivery at the Salinas outreach meeting in winter, 2015.

Workplan year 3:
Task 1. Conduct 1 to 2 field trials (1 broccoli trial, 1 potential redo trial) at the USDA Spence research farm,

Subtask 1. Identify field sites, leach fields as required to reduce residual soil NO_3-N.
Subtask 2. Establish broccoli/lettuce crops, install irrigation /fertigation systems, and conduct trials.

Task 2. Conduct outreach activities

Subtask 1.
Prepare and publish written summaries in UC and trade publication outlets.
Subtask 2. Prepare and make summary powerpoint presentation accessible on UC web outlets.
Subtask 3. Present summary information at the annual Salinas Irrigation and Nutrient management meeting.

Task 3. Incorporate findings into the 'CropManage' web-based irrigation and N management tool.

Task 4. Analyze data, prepare reports for FREP.

Subtask 1. Analyze and organize field data.
Subtask 2. Prepare and submit interpretive summary, final report, and summary powerpoint presentation to FREP.

F. Project management, evaluation and outreach:

The project leaders will collaboratively plan all field activities and outreach efforts. Conducting field trials will be the primary responsibility of Richard Smith (nutrient issues) and Michael Cahn (irrigation issues). Tim Hartz will provide expertise in data analysis and interpretation. Mike McCullough will provide background expertise on recycled water chemistry. Outreach efforts will begin following the 2013 field experiments with a presentation at the annual irrigation and nutrient management meeting in Salinas organized by Smith and Cahn, and at least one presentation at other grower educational meetings. Following the completion of field trials in 2014, the findings of this project will be incorporated into the 'CropManage' web-based irrigation and N management tool currently being developed by Cahn (ucanr.org/cropmanage). This tool provides growers with an estimate of the N requirement for lettuce based on the soil nitrate quick test, an estimate of the crop N uptake requirement, and crop residue and soil mineralization rates (Cahn et al. 2011). The addition of an algorithm for estimating the fertilizer value of NO_3/NH_4 in irrigation water will improve the efficacy of this tool. We will also develop a downloadable spreadsheet tool for estimating the fertilizer value of N in irrigation water. Additionally, written summaries of the results, and their implications for fertility and irrigation management, will be placed in UC electronic newsletters and blogs that cover the coastal production districts (Salinas, Santa Maria and Ventura), and in relevant industry trade publications. A powerpoint presentation will be prepared for inclusion on the FREP website, the UC Vegetable Research and Information (VRIC) website (http://vric.ucdavis.edu/), and the UC Nutrient Management website (http://ucanr.org/sites/nm/).

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