CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE
FERTILIZER RESEARCH AND EDUCATION PROGRAM

Final Report: January 1, 2013 – December 31, 2016

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

CDFA Agreement 12-0455-SA

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B. 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.

C. Abstract:

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. 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. The purpose of this project was to develop information and guidelines for utilizing ambient N in irrigation water for lettuce and broccoli, the main crops produced in this region. A total of 7 replicated field trials were conducted in the Salinas Valley from 2013-15. Three trials focused on determining the efficiency of lettuce and broccoli to recover N from irrigation water, as affected by concentration and irrigation efficiency. The remaining trials examined the practical contribution of irrigation water N to crop fertility under a range of typical irrigation and N fertigation regimes. This project had 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.

We have completed all field trials evaluating the effect of ambient N concentration in irrigation water on crop N uptake. Data analyzed from these trials indicated a strong yield response to the nitrate-N concentration in irrigation water over the range of 3 to 45 ppm. The results showed that N in irrigation water has the same nutrient value for lettuce and broccoli as fertilizer nitrogen. Leaching fractions as high as 40% did not reduce yield or N uptake efficiency from water in lettuce grown using drip. Yield and N uptake efficiency were reduced in broccoli irrigated using high N water under drip with a 42% leaching fraction. However, reductions in yield and N uptake efficiency under a 42% leaching fraction were similar for treatments receiving only fertilizer N.

D. Introduction:

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 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 developed data to address these questions.

E. Work Description:

Workplan year 1:

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

<u>Subtask 1.</u> Identify field sites, leach fields as required to reduce residual soil NO_3-N. Completed May 2013.

<u>Subtask 2.</u> Establish lettuce crops, install irrigation/ fertigation systems, and conduct trials. Completed October 2013.

Two field trials were completed at the USDA-ARS Spence research facility near Salinas in 2013 to address objective 1. Trials 1 and 2 were planted on May 16th and August 18th, respectively. We designed and developed a manifold and injection system to simulate water of varying NO_3-N and NH_4-N contents. Water of varying N concentrations was applied to the different treatments throughout the drip phase of the crop.

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

Subtask 1. Analyze and organize field data. Completed January 2014.
Subtask 2. Prepare and submit interim report and interpretive summary to FREP. Completed September 2013.
Subtask 3. Prepare presentation for delivery at the Salinas outreach meeting in winter, 2014. Completed February 2014.

We have analyzed of data from the 2 lettuce irrigation trials. The interim report and interpretive summary have been delivered to FREP. We presented a summary of the results of the 1st year of trials at the annual Irrigation and Nutrient Meeting that was held in Salinas on Feb. 12, 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. Completed May 2014.
Subtask 2. Establish lettuce/broccoli crops, install irrigation/ fertigation systems, and conduct trials. Completed October 2014.

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

Subtask 1. Analyze and organize field data. Completed February 2015.
Subtask 2. Prepare and submit interim report and interpretive summary to FREP. Completed September 2014.
Subtask 3. Prepare presentation for delivery at the Salinas outreach meeting in winter, 2015. Completed February 2014.

Data analysis, reports and presentations were prepared during 2014 and the winter of 2015. Interim reports and interpretive summaries were delivered to FREP in 2013 and 2014. We presented a summary of the first and 2nd year results at the annual Irrigation and Nutrient Meeting that was held in Salinas on Feb. 27th, 2015. A field day was also held in conjunction with the California Leafy Green Research Board to view the broccoli trial in October – 2014. Additionally, results were presented at CCA nutrient management trainings held in San Luis Obispo, in 2015. Other presentations on trial results are summarized in Table 6.

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. Completed May 2015.

Subtask 2. Establish broccoli/lettuce crops, install irrigation /fertigation systems, and conduct trials. Completed October 2015.

Two field trials were completed at the USDA-ARS Spence research facility near Salinas in 2015 to address objective 2. An iceberg lettuce trial was planted May 8th and a broccoli trial was planted on July 12th. Because yield and N uptake response was low in the 2014 trials for lettuce due to high residual soil N, a lettuce trial was repeated in 2015. Modifications to the trial design were made to better evaluate the effect of leaching fraction on crop N uptake.

Task 2. Conduct outreach activities

Subtask 1.

Prepare and publish written summaries in UC and trade publication outlets. Completed September 2016.

Subtask 2. Prepare and make summary powerpoint presentation accessible on UC web outlets. Completed February 2015.

Subtask 3. Present summary information at the annual Salinas Irrigation and Nutrient Management meeting.

We published project results in a trade journal article, and in two blog articles (see summary below). In addition, the articles were adapted for an AgAlert article. A powerpoint presentation that summarizes the results is available at the Monterey County UCCE website (http://cemonterey.ucanr.edu/files/234209.pdf). Also, a peer-reviewed article entitled "The fertilizer value of nitrogen in irrigation water" was accepted for publication in California Agriculture.

A total of 19 oral presentations about the project results are summarized in Table 15 in section H.

Cahn, M., T Hartz, R. Smith, L Murphy 2016 Pump and Fertilizer: factoring nitrogen from irrigation water into nutrient budgets. Salinas Valley Agriculture Blog. Posted Sept 30, 2016. http://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=22229

Cahn, M., 2016. Pump and fertilize: How to factor irrigation water into nitrogen budgets. View from the West. American Vegetable Grower Magazine. Sept 2016. p. 30-31.

Cahn, M., and R. Smith 2016. Does nitrate make your irrigation water saltier? Salinas Valley Agriculture Blog. Posted June 2, 2016. 2016. http://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=21201

Johnson, B. 2017. Nitrogen in irrigation water benefits vegetable crops. Ag Alert. January 18, 2017. http://www.agalert.com/story/?id=10479

Task 3. Incorporate findings into the ‘CropManage’ web-based irrigation and N management tool. Completion expected by June 1, 2017.

This task is in progress. UC ANR contracted Breyta Inc. to add a module that factors in the N concentration of the irrigation water into the CropManage N recommendation. The modifications are expected to be completed by June 1, 2017.

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.

An interpretive summary and interim report were submitted in 2015. The final report has been completed for the project. A summary powerpoint presentation has been completed (refer to task 3).

Field Trial Methodology

Seven field trials were conducted at the USDA-ARS Spence Rd. Research Farm near Salinas CA to investigate the fertilizer value of ambient levels of N in irrigation water for vegetable crops. Trials were conducted for crisphead (iceberg) lettuce and broccoli over the 3 years of the project (Table 1). Trials 1,2, and 5 were conducted to address objective 1, and trials 3,4,6, and 7, were conducted to address objective 2 of the project.

Year 1 (2013)

Replicated field trials (summer and fall harvested crops) were conducted on the USDA Spence research facility near Salinas in 2013 to address objective 1 for lettuce. The irrigation water available at this facility contains approximately 2 to 3 PPM NO_3-N. The soil at the farm was a Chualar sandy loam. Before planting, fields were sprinkler irrigated to leach residual NO_3-N so that each trial was conducted with low background soil N. The experimental design for each trial was a randomized complete block, with four replications. Individual plots measured 4, 40-inch wide beds × 45 ft. Crisphead lettuce (*cv.* Telluride) was seeded on the beds in 2 rows, space 12 inches apart, and germinated and established using overhead sprinklers. After thinning plants to a final stand, the field was irrigated with surface placed drip tape. The application rate of the tape was 0.45 gpm per 100 ft of tape length at 8 psi. Lettuce growth and N uptake were compared across a range of treatments simulating different levels of ambient N in irrigation water during the drip phase of the crop. Nitrogen treatments ranged from 2 to 42 ppm NO_3-N and were compared to an unfertilized control and a fertilized standard treatment (seasonal total of 150 lb N applied in weekly fertigations). In addition, we included a treatment to evaluate crop N recovery from water dominated by NH_4-N.

To observe the interaction of irrigation efficiency and crop nitrogen recovery, each N treatment was evaluated at two levels of applied water [Trial 1: applied water = 110%

and 170% of crop evapotranspiration (ET), Trial 2: applied water = 120% and 210% of crop ET]. Crop ET was estimated using reference ET values obtained from the nearest CIMIS station (214) and crop coefficients estimated by the method described by Gallardo et al. (1996). Applied water relative to estimated crop ET was higher in the fall compared to the spring trial in order to attain an adequate range of applied N rates under the various water treatments. Water-powered proportional injectors were used to enrich all drip applied water to the target concentrations of treatments (Fig. 1). Injected NO_3-N was a blend of $Ca(NO_3)_2$ and $NaNO_3$ to maintain the cation balance in the water. Injected NH_4-N was in the form of NH_4SO_4. An emitter inserted into the drip lines collected a composite water sample from each N treatment to confirm that target N concentrations were attained. The fertilized control received N in the form of AN-20. All treatments received applications of anticrustant at planting to improve germination which contained 17 and 38 lbs of N/acre for trials 1 and 2, respectively.

Nitrogen contributed from the water was calculated for each treatment from the average concentration of N measured in the water treatment× volume of applied water using equation 1:

Applied N (lbs/acre) = applied water (inches) × N concentration of water (ppm N) × 0.23 [1]

Total N applied from the water treatment was the sum of the N contributed from the water and any applied fertilizer N (anti-crustant + fertigation).

Figure 1. Manifold and injection system used for simulating irrigation water with different concentrations of nitrate-N.

Field data Collection Canopy cover of the treatments were estimated using a near-infra-red digital camera at weekly intervals. Flow meters were used to determine the volume of water applied to the standard and high water treatments. In both trials soil samples were collected at 0-1 ft and 1-2 ft prior to the initiation of N treatments, and at harvest; field-moist samples were 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 were harvested when the fertilized control treatment reached commercial maturity. Plant above-ground fresh and dry weight, and biomass N content, were determined.

Data analysis Effects of the water treatments on fresh biomass yield, plant weight, tissue N content, and plant N uptake were analyzed using SAS regression and general linear means procedures. Means separation and orthogonal contrasts were also used to determine significant differences among treatments at the $p < 0.05$ level

Crop N recovery analysis N recovery efficiency (NRE) from irrigation water was calculated for individual treatments using equation 2:

$$\text{NRE (\%)} = [(\text{BiomassN}_i - \text{BiomassN}_0)/(\text{waterN}_i - \text{waterN}_0] \times 100 \qquad [2]$$

where $BiomassN_i$ is the N (lb/acre) in the crop biomass of treatment *i*, $BiomassN_0$ is the N in the biomass of the unfertilized control treatment (0 N added), and $waterN_i$ is the total N applied to the crop through the irrigation water treatment *i* and $waterN_0$ is the total N applied in the unfertilized control (background N in irrigation water). Average NRE was determined by linear regression of N applied (independent variable) vs. Crop N uptake (dependent variable) for of the water treatments using SAS regression procedures. The slope of the relationship equaled average NRE.

Year 2 (2014)

Three replicated field trials were conducted on the USDA Spence research facility near Salinas to address objective 1 (broccoli) and objective 2 (lettuce).

Broccoli trial A field trial was conducted 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 was 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 were adapted to broccoli:

1. Unfertilized control (approximately 2 PPM NO3-N in the irrigation water)
2. fertilized control (seasonal total of 225 lb N applied in weekly fertigations)
3. 10 PPM NO3-N in irrigation water
4. 20 PPM NO3-N in irrigation water
5. 40 PPM NO3-N in irrigation water
6. 40 PPM mineral N (10 PPM NO3-N and 30 PPM NH4-N in irrigation water, simulating MRWPCA recycled water)

Similar to the lettuce trials, each of these treatments was evaluated at two levels of applied water (110% and 160% of Crop ET) to evaluate the interaction of irrigation efficiency and nitrogen recovery efficiency (NRE). The experimental design was a randomized complete block, with four replications. Each of the 48 individual plots were four 40-inch wide beds by 40 ft, with all data collected from the middle beds. Broccoli (*cv.* Patron) was seeded in 2 rows per bed, and germinated and established with sprinklers. Procedures for pre-leaching residual soil NO3-N, simulating varying levels of ambient N in irrigation water, and estimating crop ET, followed the same procedures described for the year 1 trials.

Data collection Data collected from each trial included plant above-ground fresh and dry biomass, and biomass N content. Plant N status was determined on a composite biomass sample from each plot. The crop was harvested twice to determine marketable yield. Soil sampling was conducted as described for the 2013 trials. Canopy cover of the treatments was estimated using a near-infra-red digital camera at weekly intervals. Flow meters were used to determine the volume of water applied to the 110% and 150% ET treatments.

Lettuce trials Two trials (spring and summer) were conducted to address objective 2. The crops were established using the same procedures as described for the 2013 trials. Replicated plots of lettuce (*cv*. Telluride) were fertigated with 4 levels of N fertilizer (seasonal totals of 0, 50, 100 or 150 lb N from AN-20). Each N fertigation had 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 were produced with drip irrigation applied at 110% of calculated crop ET, determined as previously described. Three additional treatments were included to test the effects of a higher leaching fraction irrigated at approximately 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 were arranged in a randomized complete block experimental design. There were four replicate plots of each treatment combination, with individual plots measuring 4 beds x 40 ft. As in 2013, the fields were sprinkler irrigated to leach residual NO_3-N so that each trial could be conducted with low background N availability.

The same procedures described for year 1 lettuce trials were followed for simulating water N treatments, collecting field data, assessing crop biomass and N uptake, and data analysis.

Year 3 (2015)

Two replicated field trials were conducted on the USDA Spence research facility near Salinas to address objective 2. Similar to the previous trials, fields were sprinkler irrigated to leach residual NO_3-N before planting so that each trial was conducted with low background soil N. The experimental design for each trial was a randomized complete block, with four replications. Individual plots measured 45 ft × 4, 40-inch wide beds. The spring crop was crisphead lettuce (*cv.* Telluride) and the fall crop was broccoli (cv. Patron). Both crops were seeded on the beds in 2 rows, spaced 12 inches apart, and germinated and established using overhead sprinklers. After stand establishment, the field was irrigated with surface placed drip tape. The application rate of the tape was 0.45 gpm per 100 ft of tape length at 8 psi. Crop growth and N uptake were compared across a range of treatments simulating different levels of N in irrigation water during the drip phase of the crop. Nitrogen treatments ranged from 4 to 45 ppm NO_3-N and were compared to fertilized N treatments as summarized in Tables 1 and 2.

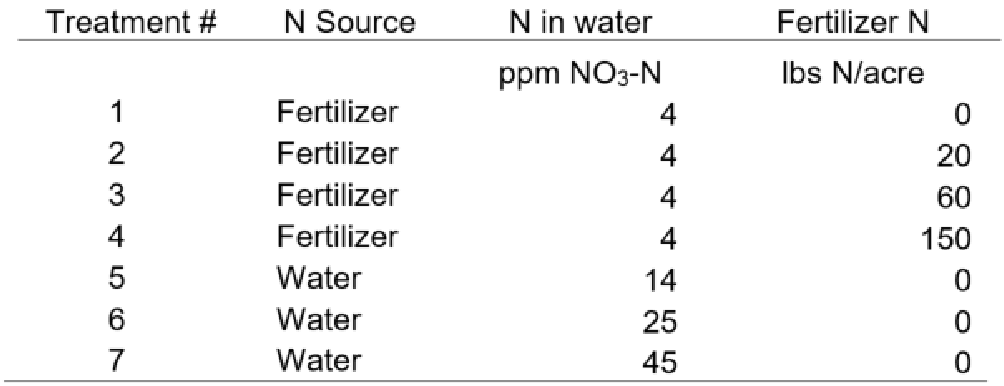
To observe the interaction of irrigation efficiency and crop nitrogen recovery, each N treatment was evaluated at two levels of applied water that were designated as Standard and High water treatments. [Trial 1: Standard and High water treatments equaled 110% and 170% of crop evapotranspiration (ET), Trial 2: Standard and High water treatments equaled 110% and 180% of crop evapotranspiration (ET)]. Crop ET was estimated using reference ET values obtained from the nearest CIMIS station (214) and crop coefficients estimated by the method described by Gallardo et al. (1996). Application of 110, 170, and 180% of Crop ET would equal leaching fractions of 10, 41, and 44%, respectively. Applied water volumes for establishment and post-establishment are presented in Tables 3 and 4. Because soil mineral N levels were high after establishment, extra water was applied during the first 1 or 2 irrigations with the drip system to lower residual N levels before beginning the N treatments.

Crop N uptake for the spring lettuce trial was determined following the same procedures described for year 1 lettuce trials. Procedures for determining crop N uptake of the broccoli trials were the same as described previously for the year 2 broccoli trial. In addition, methodologies for the simulating N water treatments, in season field data collection, and data analysis were the same as previous years.

Table 1. Summary of 7 field trials conducted at the USDA-ARS Spence Rd research farm near Salinas CA to evaluate the fertilizer value of N in irrigation water.

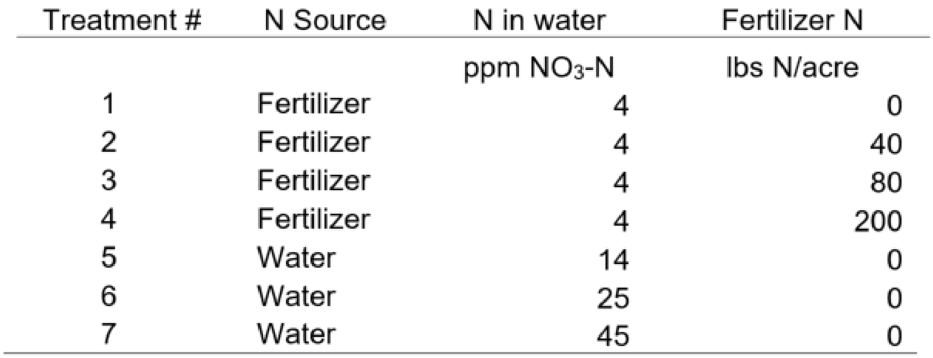
Trial	Year	Season	Crop	Plant date	Harvest date	Cultivar	Anticrustant N	Maximum Fertilizer N Treatment	Standard Water Treatment	High Water Treatment
							------- lbs N/acre	------	---- % Crop ET	----
1	2013	summer	lettuce	5/16/2013	7/24/2013	Telluride	18	150	110	160
2	2013	fall	lettuce	8/14/2013	10/31/2013	Telluride	38	150	120	220
3	2014	summer	lettuce	4/30/2014	7/7/2014	Telluride	27	150	110	170
4	2014	fall	lettuce	6/27/2014	9/2/2014	Telluride	24	150	110	170
5	2014	fall	broccoli	8/7/2014	11/3/2014	Patron	22	220	110	180
6	2015	summer	lettuce	5/8/2015	7/13/2015	Telluride	22	200	110	170
7	2015	fall	broccoli	7/12/2015	10/12/2015	Patron	22	200	110	180

Table 2. Nitrogen treatments for summer iceberg trial (Trial 6).



Treatment #	N Source	N in water	Fertilizer N
		ppm NO_3-N	lbs N/acre
1	Fertilizer	4	0
2	Fertilizer	4	20
3	Fertilizer	4	60
4	Fertilizer	4	150
5	Water	14	0
6	Water	25	0
7	Water	45	0

Table 3. Nitrogen treatments for fall broccoli trial (Trial 7).



Treatment #	N Source	N in water	Fertilizer N
		ppm NO_3-N	lbs N/acre
1	Fertilizer	4	0
2	Fertilizer	4	40
3	Fertilizer	4	80
4	Fertilizer	4	200
5	Water	14	0
6	Water	25	0
7	Water	45	0

Table 4. Water volumes applied for establishment and post-establishment of the summer lettuce crop (Trial 6).

Irrigation Treatment	crop establishment sprinkler+drip[1]	post-establishment drip
	-------- inches ---------	
Standard (110% ETc)	7.8	4.0
High (170% ETc)	7.8	6.6

[1] 5.1 inches applied by drip to reduce soil mineral N levels prior to post-establishment treatments

Table 5. Water volumes applied for establishment and post-establishment of the fall broccoli crop (Trial 7).

	Applied Water	
Irrigation Treatment	crop establishment sprinkler+drip[1]	post-establishment drip
	-------------------- inches ------------------	
Standard (110% ETc)	5.3	10.2
High (180% ETc)	5.3	17.0

[1] additional 0.5 inches applied by drip to reduce soil mineral N levels prior to post-establishment treatments

F. Results

Year 1 (2013 trials):

The average NO_3 and NH_4 concentrations of the irrigation treatments were very close to the target concentrations (Tables 6 and 7), which confirmed that the methodology used to simulate irrigation water with different nitrate concentrations was accurate and reliable.

Results of the summer and fall trials demonstrated that the concentration of nitrogen in the irrigation water significantly affected lettuce plant size, N content of tissue, biomass yield (Tables 8 and 9, Figs. 2-7), and confirmed that a significant portion of the N in the irrigation water was taken up by the lettuce crops. Even relatively low concentrations of NO_3-N in the irrigation water were utilized by the crop.

The response of biomass yield, plant weight, and plant N uptake to N concentration of the water treatments was greater during the summer than the fall, presumably because the N demand of the crop was greatest during the summer when growth was most rapid. The average biomass yield (88,697 lbs/acre) of the highest N rate (175 lbs

N/acre) of the summer crop was 37% greater than average biomass yield (64,791 lbs/acre) of highest N rate (195 lbs N/acre) for the fall crop. Also, N uptake of the summer crop at the highest N rate was 42 lbs N/acre greater for the summer than the fall crop. In contrast, the N content of the plant tissue at the highest N rate was highest in the fall crop (Tables 8 and 9), indicating that the fall crop was taking up N but grew at a slower rate than the summer crop.

The volume of water applied to the crops did not affect the recovery of N from the water treatments, which would suggest that all of the applied water could be credited as having N value to the crop. All treatments fit similar quadratic relationships for the fall and summer crops as shown in Figs. 2-7. The relationship between applied N and crop N uptake for the fertigation and water N treatments fit the same quadratic response curve ($R^2 = 0.99$, $p < 0.0001$) which would suggest that the crop recovery of N from the water and fertilizer would likely be similar at the same applied rates.

Average NRE was determined for each trial from the slope of a linear plot of the amount of N applied by water and crop N uptake (Figs. 8 and 9). Crop recovery of N from the water treatments averaged 86% during the summer (Fig. 8) and 41% (Fig. 9) during the fall trials. As mentioned before, the higher recovery during the summer reflects the fact that the crop was growing more vigorously than during the fall. The source of N in the irrigation water (NH_4 vs NO_3) had no significant effect on N recovery by the crop (Figs. 10 and 11).

Year 2 (2014) trials

Lettuce trials

Both summer and fall harvested lettuce trials in year 2 compared treatments receiving only fertilizer N to treatments receiving a combination of N from fertilizer and water sources. Soil nitrate levels in the 0-1 foot depth before planting were greater than 15 ppm NO_3-N, equivalent to > 50 lbs N/acre for both trials. The high residual N at planting was likely caused by a lack of rainfall during the winter which would normally leach a portion of the residual soil nitrate. Consequently, although biomass yield, crop N uptake, and N content of tissue varied significantly among N treatments (Tables 11 and 12), the differences among treatments were small relative to treatment differences measured during the first year of trials (Figs. 12-17). Nevertheless, as was found for the first year of trials, all N treatments could be described by the same quadratic regression curve, which would suggest that the biomass yield, crop N uptake, and tissue N concentration response to applied N was similar for both fertilizer and water sources of nitrogen. Further analysis by multivariate regression demonstrated that the percentage of N applied from fertilizer did not significantly affect biomass yield and crop N uptake for both the summer and fall harvested crops. Increasing the volume of water applied from 110% to 170% of crop ET, also did not affect N recovery for either the summer and fall harvested crops.

Broccoli trial

Similar to the first year of lettuce trials, applying water with increasing concentrations of N increased plant weight, N content of plant tissue, biomass yield, and marketable yield

(Table 12). Nitrogen from relatively low N water concentrations (12 ppm NO3-N) was taken up by broccoli. The form of nitrogen in the water treatments (NH_4-N *vs* NO_3-N) did not significantly affect N recovery or crop growth. Both fertilizer and water sources of N resulted in similar responses in biomass, marketable yield, and crop N uptake, (Figs. 18-20), suggesting that again that both fertilizer and water sources of N have the same effect on crop growth and on N recovery. However, the high water treatment (180% ETc) that presumably would promote NO_3-N leaching, did affect crop recovery of N (Fig. 20). However, the reduction in N recovery was similar among the fertilizer and water treatments irrigated to 180% of crop ET, again suggesting that crop uptake of N from water and fertilizer were equivalent.

Year 3 (2015 trials):

Results of the lettuce and broccoli trials demonstrated that the concentration of nitrogen in the irrigation water significantly affected plant size, N content of tissue, biomass yield and marketable yield (Table 13, Figs. 21-26), and confirmed that a significant portion of the N in the irrigation water was taken up by the crops. Even relatively low concentrations of NO_3-N in the irrigation water (14 ppm N) were recovered by the crops.

Lettuce trial
Biomass yield response to applied N was similar for water and fertilizer sources of N (Fig. 21). Biomass yield response to applied N was also similar for high and standard water rates.

Treatment effects on N uptake of lettuce followed a similar pattern as biomass yield (Fig. 22). Treatments receiving N from water had a statistically similar effect on crop N uptake as treatments receiving N from fertilizer. N uptake of lettuce increased with increasing concentrations of NO_3 in the irrigation water and with higher amounts of applied water. The field trial results also demonstrated that the leaching fraction associated with the high water treatment did not affect the recovery of N from the water treatments, and therefore all of the applied water could be credited as having N value to the crop. For applied N rates ranging from 25 to 90 lbs N/acre, crop N recovery efficiency (NRE) averaged 45% and 35% from water and fertilizer N treatments, respectively.

The N content of the tissue was also significantly affected by the N concentration in the water and the amount of fertilizer N applied (Table 13, Fig. 23). The N content of lettuce tissue increased with greater concentration of NO_3 and volume of applied water. The water N treatments had a similar effect on the N content of lettuce tissue as the fertilizer N treatments.

Broccoli trial
Similar to past trials, applying water with increasing concentrations of N increased plant weight, N content of plant tissue, biomass yield, and marketable yield of broccoli (Table 14). N was taken up by broccoli even at relatively low concentrations in the water (13 ppm NO_3-N).

In contrast to the lettuce trial, the volume of water applied to broccoli affected recovery of N from the fertilizer and water N treatments (Fig. 24). N recovery was significantly lower for N treatments receiving high water volumes (180% Crop ET) compared to N treatments receiving a standard water volume (110% Crop ET). The reduction in N recovery under the high leaching fraction treatment (180% Crop ET) was greater for treatments with a fertilizer source of N than treatments with a water source of N (Fig. 25). Average NRE was 65% from fertilizer sources of N and 73% from water sources of N. The high water rate also reduced marketable yield for treatments receiving N from fertilizer more than from water (Fig. 26). The highest yielding treatment received all N from water (Table 14).

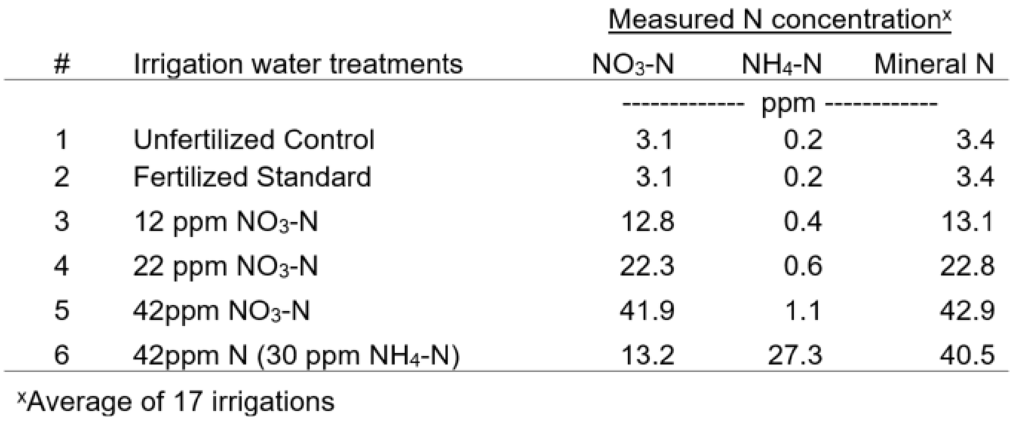
G. Discussion and Conclusions

The results of 7 replicated field trials conducted during 2013-2015 demonstrated that ambient N in irrigation water has fertilizer value for shallow rooted vegetable crops such as lettuce as well as deeper rooted vegetables such as broccoli, even when the N concentration in the water was low (12 ppm N). The trials also showed that the source of N (NH_4 *vs* NO_3) did not affect crop recovery. Presumably NH_4 would quickly transform to NO_3 when added to the soil.

The volume of water applied (leaching fraction) did not affect the recovery rate of N in lettuce but did affect recovery in broccoli. Although broccoli is a deeper-rooted crop than lettuce, it has a higher N demand. Low soil nitrate levels during the midseason may have impacted growth and yield of broccoli. However, the reduction in N recovery under the high water treatment was shown to be similar as when a fertilizer source of N was used. This result suggests that all water applied containing N can be credited as having fertilizer value to the crop. These results were attained under a well-managed drip irrigation system, with a high application uniformity and irrigations were frequent (2 to 3 times per week) so that irrigation volumes were small, which likely minimized leaching losses, even under high ET applications rates. It is possible that under poor water management or less efficient irrigation methods (e.g. furrow), recovery of N would be less than was reported in these trials. However, potential reductions in crop N recovery caused by any of these scenarios would likely be similar for fertilizer N.

These trials only evaluated N recovery from water sources of N after crop establishment, and demonstrated that growers should take credit for N in their irrigation water after crop establishment. Nitrogen in water applied during germination and establishment would likely not be utilized by the crop if the water percolates below the root system. In this phase of the crop, growers would probably only take credit for N in the water that would be used for crop evapotranspiration. Alternatively, growers could evaluate the mineral N in the soil after establishment to determine if fertilizer N is needed, which would integrate the contributions of water N with other sources of N such as from mineralization of soil and crop residue.

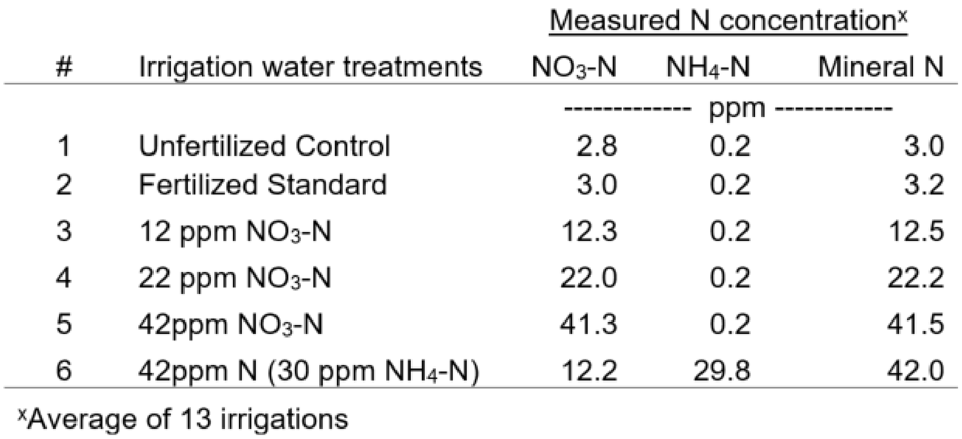
Table 6. Measured NO_3-N and NH_4-N concentrations of irrigation water treatments (trial 1, summer harvest)



#	Irrigation water treatments	Measured N concentration[x]		
		NO_3-N	NH_4-N	Mineral N
		-------------	ppm	------------
1	Unfertilized Control	3.1	0.2	3.4
2	Fertilized Standard	3.1	0.2	3.4
3	12 ppm NO_3-N	12.8	0.4	13.1
4	22 ppm NO_3-N	22.3	0.6	22.8
5	42ppm NO_3-N	41.9	1.1	42.9
6	42ppm N (30 ppm NH_4-N)	13.2	27.3	40.5

[x] Average of 17 irrigations

Table 7. Measured NO_3-N and NH_4-N concentrations of irrigation water treatments (trial 2, fall harvest)



#	Irrigation water treatments	Measured N concentration[x]		
		NO_3-N	NH_4-N	Mineral N
		-------------	ppm	------------
1	Unfertilized Control	2.8	0.2	3.0
2	Fertilized Standard	3.0	0.2	3.2
3	12 ppm NO_3-N	12.3	0.2	12.5
4	22 ppm NO_3-N	22.0	0.2	22.2
5	42ppm NO_3-N	41.3	0.2	41.5
6	42ppm N (30 ppm NH_4-N)	12.2	29.8	42.0

[x] Average of 13 irrigations

Table 8. Effect of water treatments on lettuce biomass yield, tissue N, and N uptake (trial 1, summer harvest)

	Applied N					
Irrigation water treatments	Irrigation water	Fertilizer + water	Plant tissue N content	Whole plant weight	Biomass yield	Crop N uptake
	------- lbs N/acre -----		%	lbs/plant	lbs/acre	lbs N/acre
	--------------------------------	110 % ETc	-------------------------------			
Unfertilized Control	5.3	22.9	1.4	1.3	37058	38.3
Fertilized Standard	5.3	172.9	2.5	3.1	85207	132.0
12 ppm NO_3-N	20.7	38.3	1.5	1.7	48823	50.1
22 ppm NO_3-N	35.8	53.4	1.7	1.9	54261	63.4
42ppm NO_3-N	67.3	84.9	2.0	2.6	73821	88.4
42ppm N (30 ppm NH_4-N)	63.5	81.1	2.1	2.4	67347	90.0
	-------------------------------	160 % ETc	-------------------------------			
Unfertilized Control	7.7	25.3	1.4	1.6	43158	43.3
Fertilized Standard	7.7	175.3	2.7	3.3	92187	133.8
12 ppm NO_3-N	30.0	47.6	1.8	2.2	62222	69.8
22 ppm NO_3-N	52.4	70.0	2.0	2.5	71989	87.1
42ppm NO_3-N	98.3	115.9	2.4	3.2	89175	119.9
42ppm N (30 ppm NH_4-N)	92.9	110.5	2.4	3.0	86308	117.8
$LSD_{0.05}$			0.15	0.19	4595	8.7

Table 9. Effect of water treatments on lettuce biomass yield, tissue N, and N uptake (trial 2, fall harvest).

Irrigation water treatments	Irrigation water	Fertilizer + water	Plant tissue N content	Whole plant weight	Biomass yield	Crop N uptake
	-------- lbs N/acre ---- -		%	lbs/plant	lbs/acre	lbs N/acre
		------------------------------- 120 % ETc -------------------------------				
Unfertilized Control	3.8	42.2	2.2	1.9	52896	58.1
Fertilized Standard	4.0	192.4	3.5	2.4	64263	96.3
12 ppm NO_3-N	15.5	53.9	2.4	2.1	58657	66.0
22 ppm NO_3-N	27.5	65.9	2.6	2.1	59134	71.8
42ppm NO_3-N	50.6	89.0	2.9	2.3	62443	80.3
42ppm N (30 ppm NH_4-N)	52.1	90.5	2.8	2.2	60249	77.6
		------------------------------- 210 % ETc -------------------------------				
Unfertilized Control	6.7	45.1	2.2	1.8	51080	54.1
Fertilized Standard	7.0	195.4	3.2	2.4	65319	91.4
12 ppm NO_3-N	27.0	65.4	2.4	2.0	55213	60.6
22 ppm NO_3-N	47.8	86.2	2.8	2.2	60189	75.6
42ppm NO_3-N	90.1	128.5	3.0	2.4	67128	90.1
42ppm N (30 ppm NH_4-N)	90.0	128.4	3.2	2.3	65199	92.9
$LSD_{0.05}$			0.21	0.14	4829	7.7

Table 10. Effect of water and fertigation treatments on lettuce biomass yield, tissue N, and N uptake (trial 3, summer harvest).

Irrigation water treatments	Applied N Irrigation water	Fertigation	All Fertilizer + water	Plant tissue N content	Whole plant weight	Biomass yield	Crop N uptake
	lbs N/acre			%	lbs/plant	lbs/acre	lbs N/acre
110 % ETc							
Unfertilized Control	6.0	0	30.1	2.96	2.12	65658	83.9
Fertilized	6.6	50	80.7	3.10	2.17	66281	88.4
Fertilized	6.8	100	130.9	3.36	2.26	69248	103.2
Fertilized Standard	6.1	150	180.2	3.75	2.19	69061	102.0
12 ppm NO_3-N	16.3	0	40.4	2.91	2.08	65356	85.2
12 ppm NO_3-N	16.0	50	90.1	3.38	2.19	67888	97.4
12 ppm NO_3-N	17.0	100	141.1	3.65	2.24	68147	98.2
22 ppm NO_3-N	26.7	0	50.8	3.02	2.11	64341	82.2
22 ppm NO_3-N	26.6	50	100.7	3.37	2.17	67382	91.8
22 ppm NO_3-N	26.8	100	150.9	3.69	2.28	69831	105.1
42ppm NO_3-N	50.0	0	74.1	3.38	2.24	68881	96.1
42ppm NO_3-N	48.6	50	122.7	3.62	2.30	70027	100.9
42ppm NO_3-N	49.6	100	173.7	3.83	2.25	67603	102.8
170 % ETc							
12 ppm NO_3-N	28.4	50	102.5	3.27	2.23	69440	94.0
22 ppm NO_3-N	47.5	50	121.6	3.49	2.25	68699	89.3
42ppm NO_3-N	84.6	50	158.7	3.54	2.31	72368	98.5
$LSD_{0.05}$				0.32	0.11	3385	9.8

Table 11. Effect of water and fertigation treatments on lettuce biomass yield, tissue N, and N uptake (trial 4, fall harvest).

		Applied N						
	Irrigation treatments	Irrigation water	Fertigation	All Fertilizer + water	Plant tissue N content	Whole plant weight	Biomass yield	Crop N uptake
		----------- lbs N/acre --------			%	lbs/plant	lbs/acre	lbs N/acre
		-- 110 % ETc			--------------------------------------			
1	Unfertilized Control	5.1	0	32.2	2.59	2.45	66058	87.7
2	Fertilized	4.6	50	81.7	2.99	2.56	70385	106.5
3	Fertilized	4.6	100	131.7	3.28	2.60	68051	118.9
4	Fertilized Standard	5.3	150	182.4	3.43	2.63	71399	130.8
5	12 ppm NO_3-N	13.0	0	40.1	2.67	2.49	67150	91.3
6	12 ppm NO_3-N	13.1	50	90.2	2.91	2.59	68440	104.9
7	12 ppm NO_3-N	13.1	100	140.2	3.42	2.66	71469	128.9
8	22 ppm NO_3-N	21.3	0	48.4	2.99	2.67	70025	118.1
9	22 ppm NO_3-N	21.5	50	98.6	3.16	2.66	73075	126.6
10	22 ppm NO_3-N	21.5	100	148.6	3.36	2.73	74934	121.3
11	42ppm NO_3-N	37.7	0	64.8	3.16	2.53	68363	100.8
12	42ppm NO_3-N	37.6	50	114.7	3.44	2.59	68788	132.3
13	42ppm NO_3-N	37.4	100	164.5	3.49	2.59	72025	126.3
		-- 170 % ETc			--------------------------------------			
14	12 ppm NO_3-N	18.6	50	95.7	3.22	2.79	76507	127.7
15	22 ppm NO_3-N	33.0	50	110.1	2.98	2.67	74560	96.2
16	42ppm NO_3-N	63.7	50	140.8	3.28	2.79	74857	121.8
	$LSD_{0.05}$				0.26	0.24	5907	25.9

Table 12. Effect of water treatments on broccoli biomass yield, marketable yield tissue N, and N uptake (trial 5, fall harvest)

Irrigation water treatments	Applied N Irrigation water	 Fertilizer + water	Plant tissue N content	Whole plant weight	Biomass yield	Marketable yield	Crop N upake
	-------- lbs N/acre -----		%	lbs/plant	-----lbs/acre-----		lbs N/acre
			110 % ETc				
Unfertilized Control	5.3	27.4	1.80	0.78	39042	3164	88.8
Fertilized Standard	5.3	247.4	4.03	1.46	59404	15123	212.7
12 ppm NO_3-N	21.0	43.1	1.99	0.93	43072	8099	96.1
22 ppm NO_3-N	36.4	58.5	2.33	1.01	46105	7948	122.9
42ppm NO_3-N	63.8	85.9	2.76	1.11	52523	10468	148.0
42ppm N (30 ppm NH_4-N)	67.5	89.6	2.55	1.11	53701	10736	147.3
			170 % ETc				
Unfertilized Control	9.0	31.1	1.72	0.75	34392	2901	77.5
Fertilized Standard	10.3	252.4	3.50	1.37	66295	14877	201.4
12 ppm NO_3-N	35.0	57.1	1.92	0.98	45029	4887	99.5
22 ppm NO_3-N	61.7	83.8	2.56	1.15	49157	8810	130.4
42ppm NO_3-N	109.2	131.3	2.89	1.32	59487	13296	156.8
42ppm N (30 ppm NH_4-N)	115.4	137.5	2.83	1.20	54147	12369	144.3
$LSD_{0.05}$			0.34	0.17	5452	2780	20.2

Table 13. Effect of water treatments on iceberg lettuce biomass yield, plant weight, tissue N and N uptake (trial 6, summer harvest).

	Applied N					
Irrigation water treatments	Irrigation water	Fertilizer + water	Plant tissue N content	Whole plant weight	Biomass yield	Crop N uptake
	------- lbs N/acre -----		%	lbs/plant	lbs/acre	lbs N/acre
---------------------- Standard Water (110 % ETc) ----------------------- ----						
Unfertilized Control	3.6	25.9	2.26	2.05	59442	60.1
Fertilizer 40 lbs N/acre	3.9	46.2	2.47	2.16	63672	71.2
Fertilizer 80 lbs N/acre	4.2	86.5	2.73	2.33	67216	84.9
Fertilizer 200 lbs N/acre	4.0	176.3	3.39	2.53	74301	107.0
Water N 14 ppm NO_3-N	12.9	35.2	2.27	2.01	59771	65.4
Water N 25 ppm NO_3-N	22.4	44.7	2.43	2.16	62609	75.4
Water N 45 ppm NO_3-N	40.0	62.3	2.90	2.35	67159	86.3
---------------------- High Water (170 % ETc) ----------------------- ----						
Unfertilized Control	5.8	28.1	2.30	1.88	55971	61.5
Fertilizer 40 lbs N/acre	5.9	48.2	2.29	2.09	60943	65.5
Fertilizer 80 lbs N/acre	6.3	88.6	2.87	2.34	67721	80.7
Fertilizer 200 lbs N/acre	6.0	178.3	3.30	2.60	75840	110.0
Water N 14 ppm NO_3-N	21.3	43.6	2.48	2.18	64040	76.5
Water N 25 ppm NO_3-N	36.5	58.8	2.66	2.14	63082	73.9
Water N 45 ppm NO_3-N	67.7	90.0	2.97	2.41	70765	93.1
$LSD_{0.05}$			0.30	0.13	4630	9.5

Table 14. Effect of water treatments on broccoli biomass and marketable yield, plant weight, tissue N and N uptake (trial 7 fall harvest).

	Applied N						
Irrigation water treatments	Irrigation water	Fertilizer + water	Plant tissue N content	Whole plant weight	Biomass yield	Marketable yield	Crop N uptake
	------ lbs N/acre ---		%	lbs/plant	---- lbs/acre -----		lbs N/acre
--------------------- Standard Water (110 % ETc) ------------------ ----							
Unfertilized Control	9.7	31.7	1.56	0.80	44838	2603	98.7
Fertilizer 40 lbs N/acre	9.8	71.8	1.73	0.99	55211	2995	121.3
Fertilizer 80 lbs N/acre	10.0	112.0	2.15	1.15	62551	6574	159.0
Fertilizer 200 lbs N/acre	10.6	232.6	3.16	1.43	79086	10244	236.1
Water N 14 ppm NO_3-N	34.0	56.0	1.76	0.91	52571	2709	118.3
Water N 25 ppm NO_3-N	57.6	79.6	2.02	1.03	60594	4383	144.3
Water N 45 ppm NO_3-N	105.1	127.0	2.34	1.34	67985	9724	174.0
----------------------- High Water (180 % ETc) ---------------------- --							
Unfertilized Control	15.4	37.4	1.37	0.75	39696	1167	81.7
Fertilizer 40 lbs N/acre	16.4	78.4	1.69	0.81	50935	1425	114.7
Fertilizer 80 lbs N/acre	15.7	117.7	1.63	0.97	56080	3376	118.0
Fertilizer 200 lbs N/acre	16.8	238.8	2.42	1.44	80031	9278	209.2
Water N 14 ppm NO_3-N	55.8	77.8	1.62	0.87	51212	2553	114.0
Water N 25 ppm NO_3-N	94.7	116.7	2.07	0.98	64217	5677	151.8
Water N 45 ppm NO_3-N	170.1	192.0	2.52	1.44	80561	12575	204.7
$LSD_{0.05}$			0.35	0.23	11646	1567	32.7

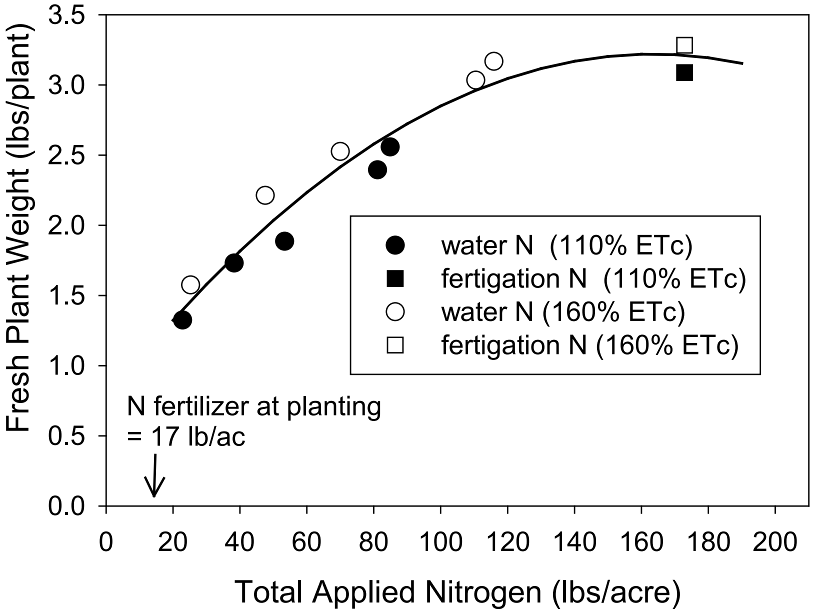


Figure 2. Effect of applied nitrogen on fresh weight of plants (trial 1, summer harvest).

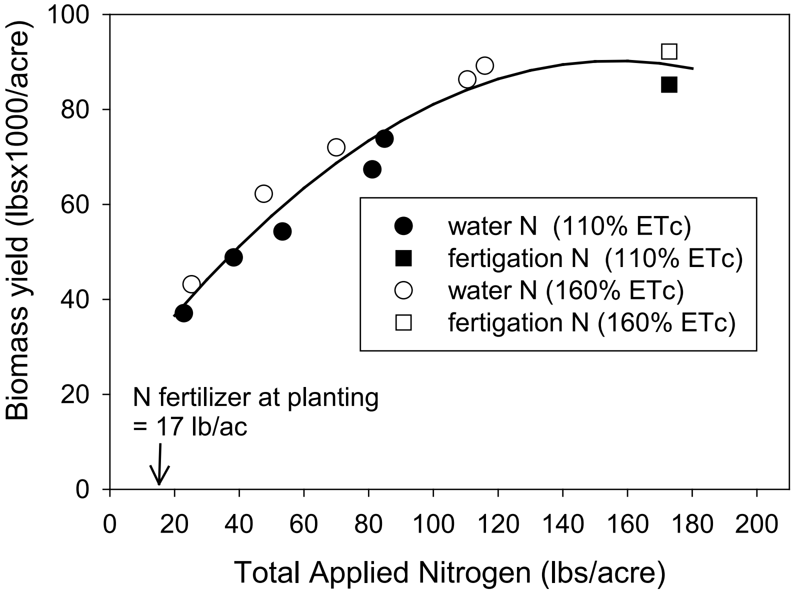


Figure 3. Effect of applied nitrogen on biomass yield (trial 1, summer harvest).

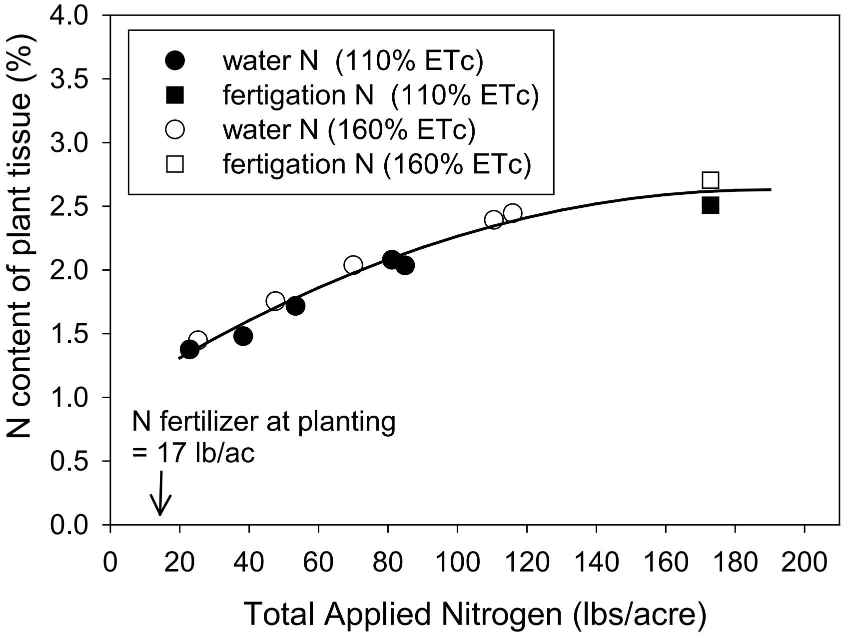


Figure 4. Effect of applied nitrogen on N content of plant tissue (trial 1, summer harvest).

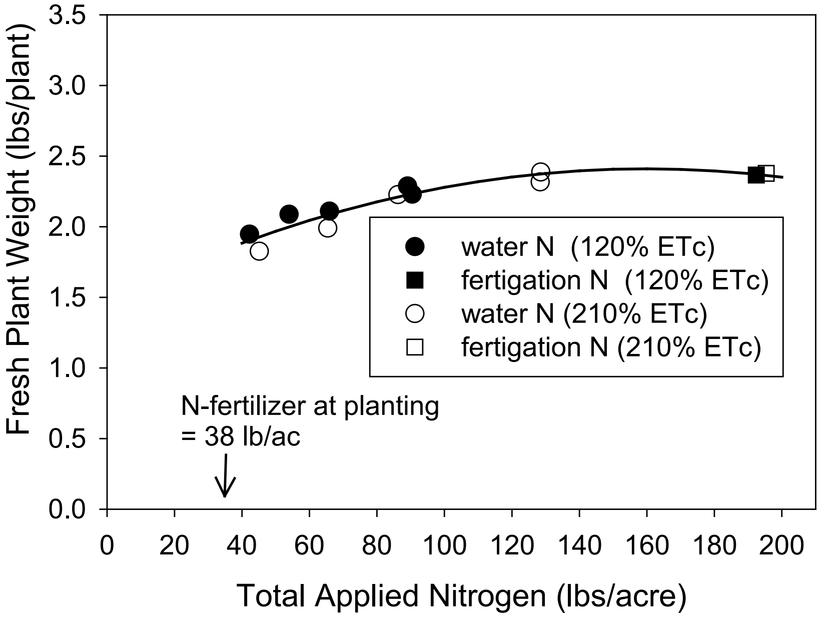


Figure 5. Effect of applied nitrogen on fresh weight of plants (trial 2, fall harvest).

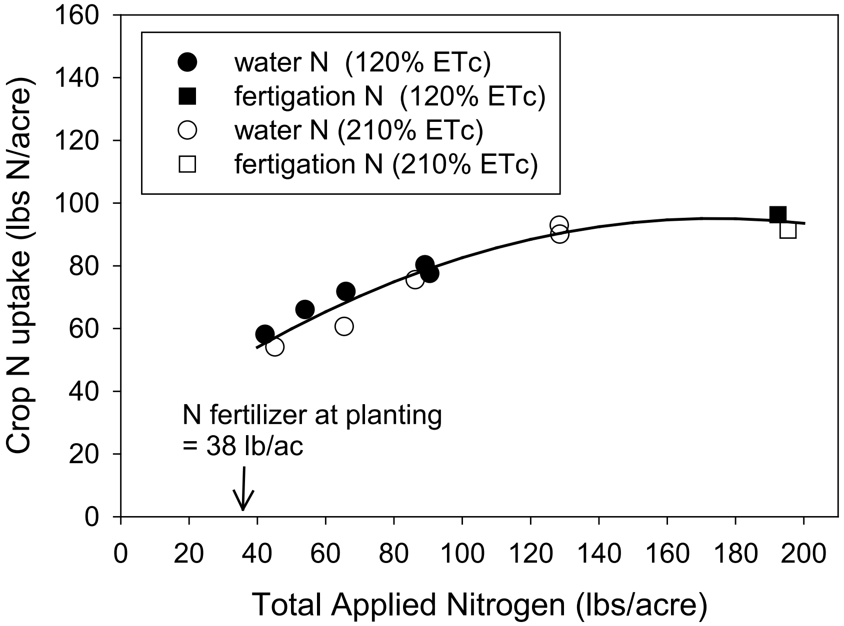


Figure 6. Effect of applied nitrogen on crop N uptake (trial 2, fall harvest).

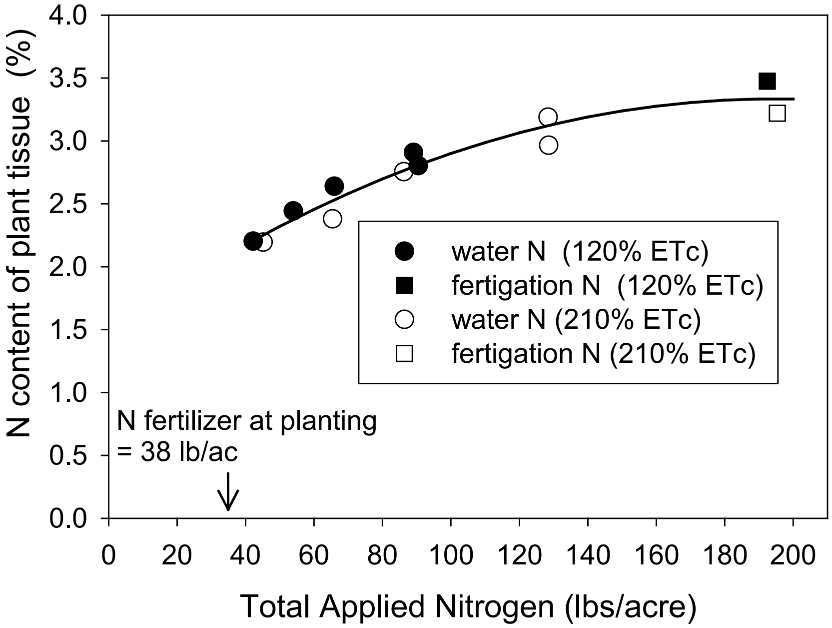


Figure 7. Effect of applied nitrogen on N content of plant tissue (trial 2, fall harvest).

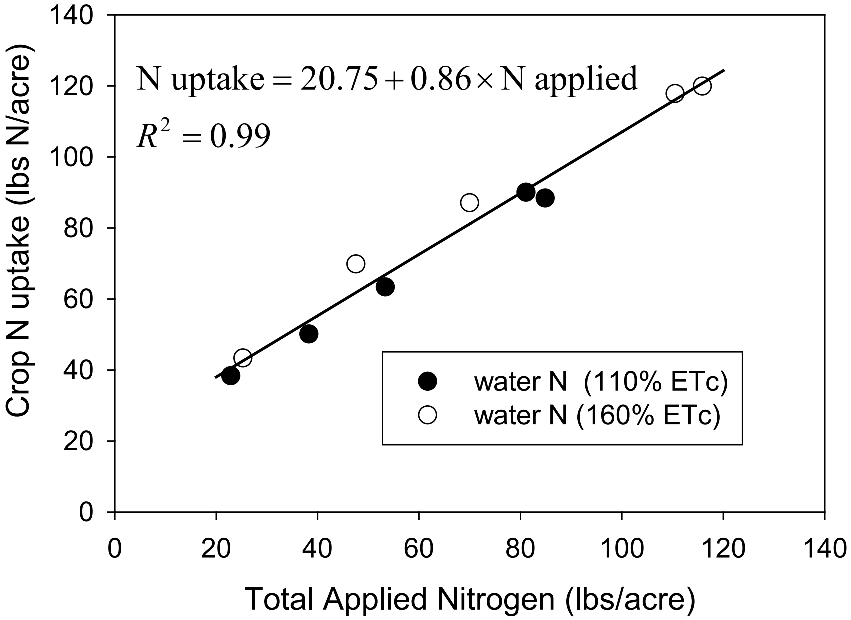


Figure 8. Effect of applied nitrogen in water treatments on crop N uptake (trial 1, summer harvest).

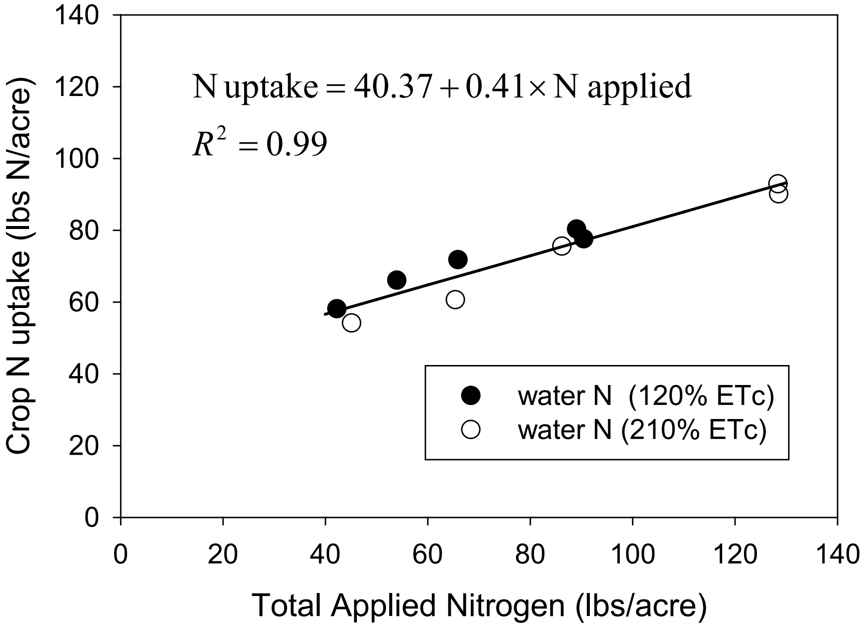


Figure 9. Effect of applied nitrogen in water treatments on crop N uptake (trial 2, fall harvest).

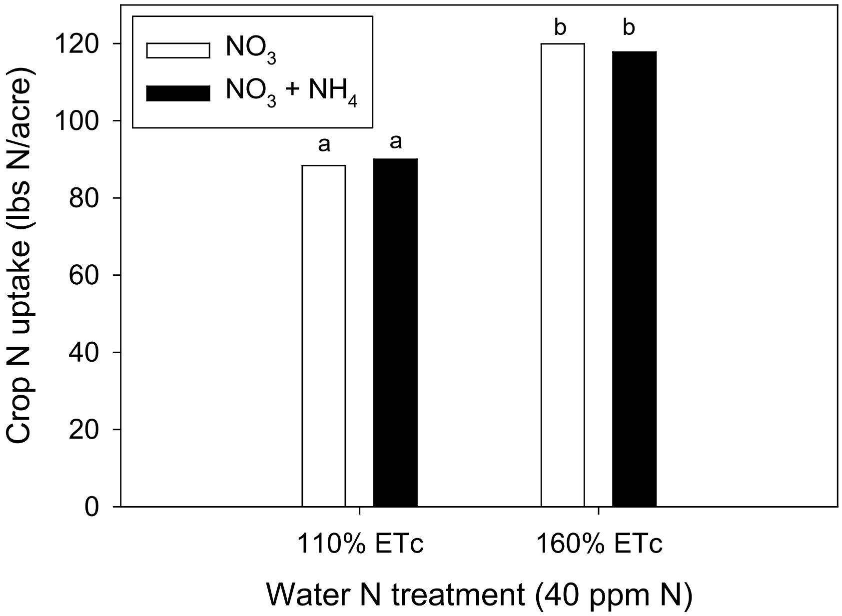


Figure 10. Effect of 40 ppm NO_3-N and NO_3+NH_4-N water treatments on crop N uptake (trial 1, summer harvest).

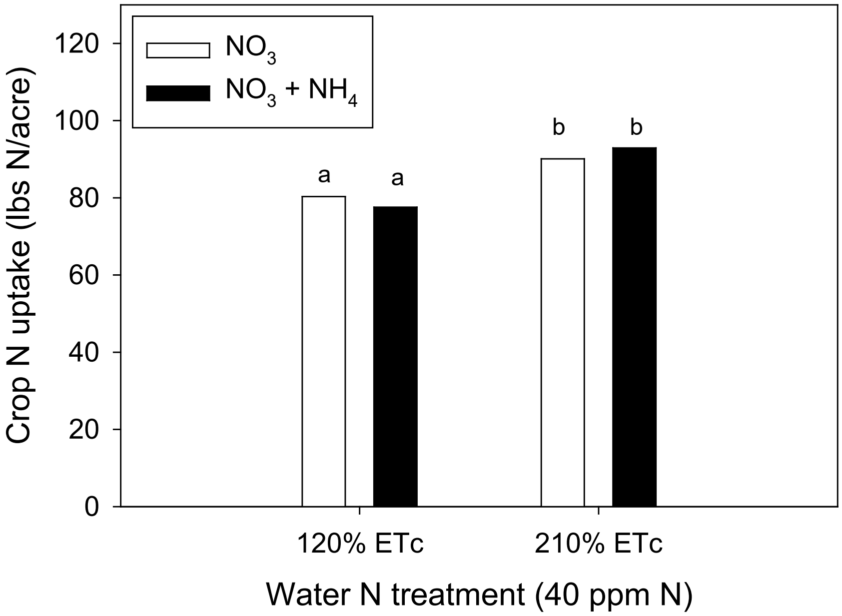


Figure 11. Effect of 40 ppm NO_3-N and NO_3+NH_4-N water treatments on crop N uptake (trial 2, fall harvest).

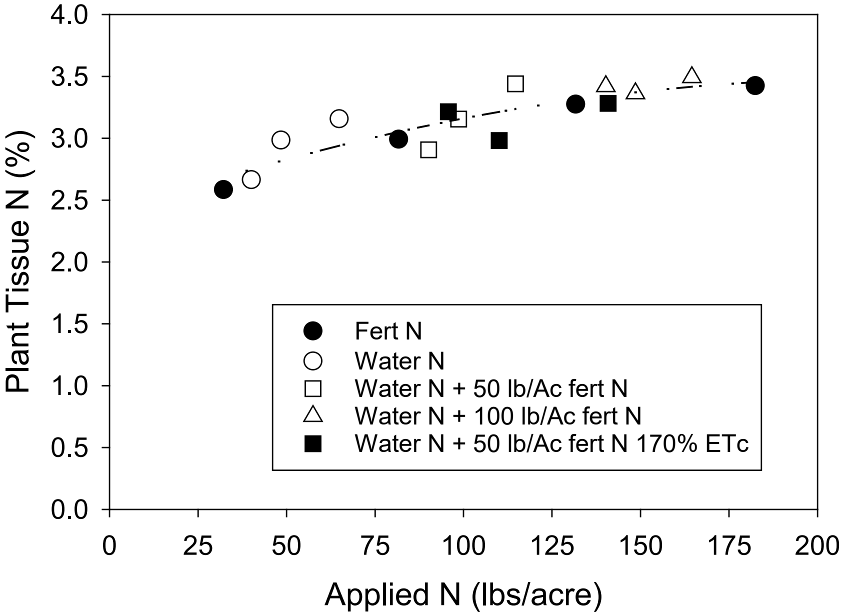


Figure 12. Effect of applied nitrogen on N content of plant tissue (trial 3, summer harvest).

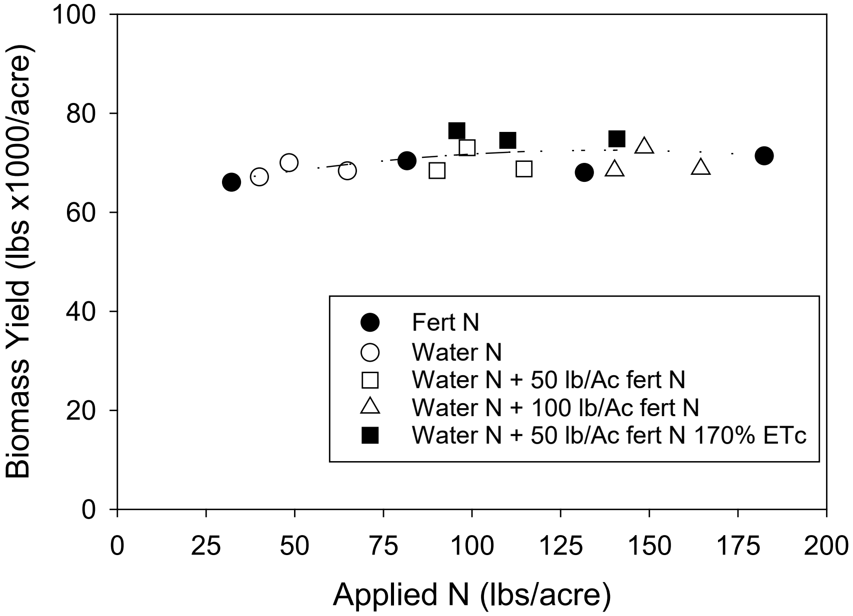


Figure 13. Effect of applied nitrogen on biomass yield (trial 3, summer harvest).

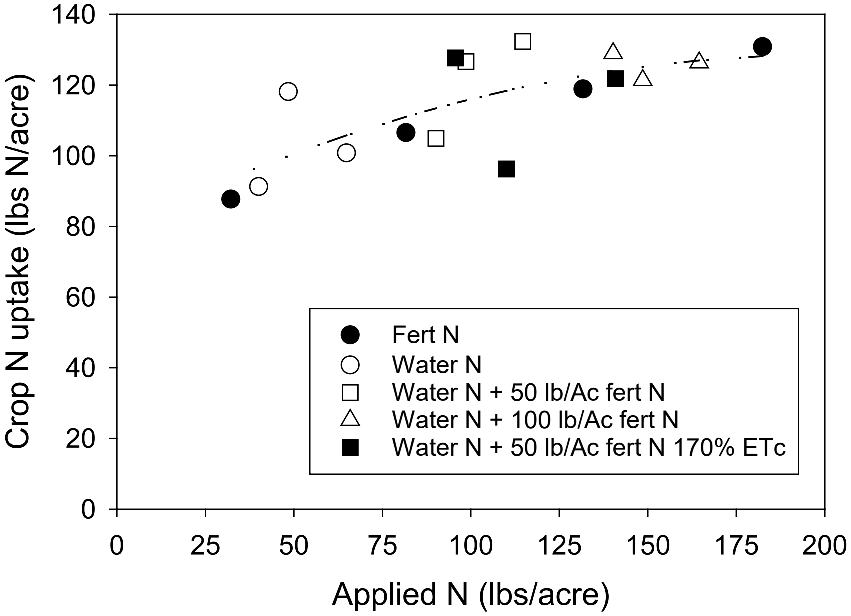


Figure 14. Effect of applied nitrogen on crop N uptake (trial 3, summer harvest).

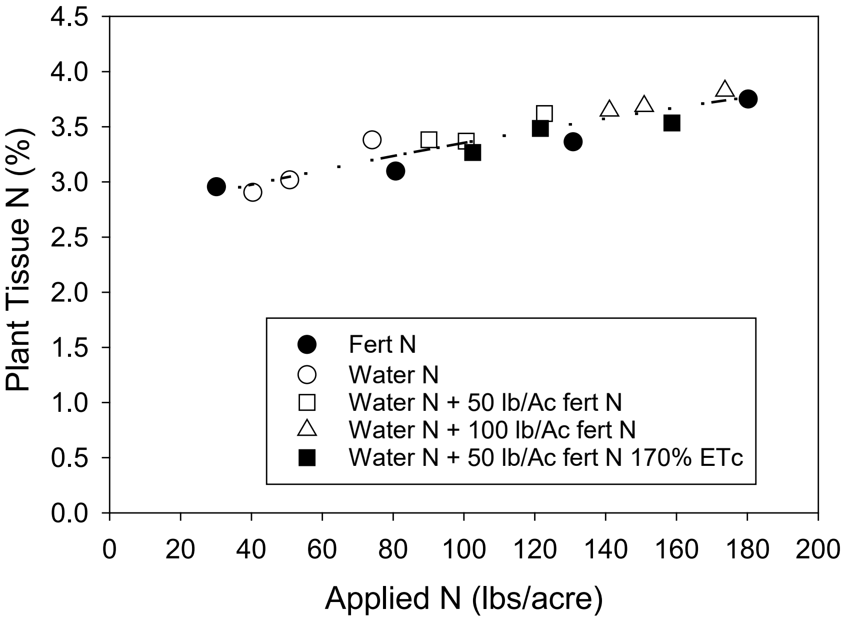


Figure 15. Effect of applied nitrogen on N content of plant tissue (trial 4, fall harvest).

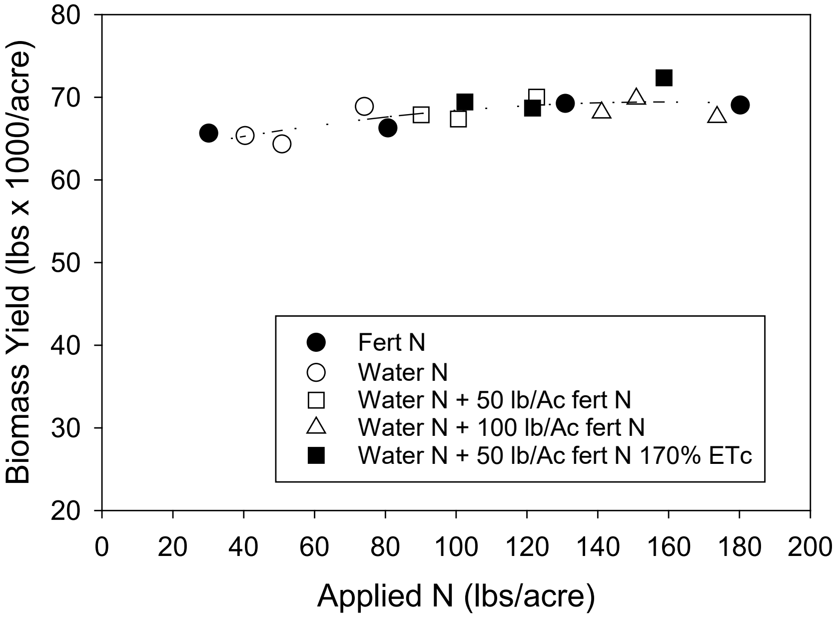


Figure 16. Effect of applied nitrogen on biomass yield (trial 4, fall harvest).

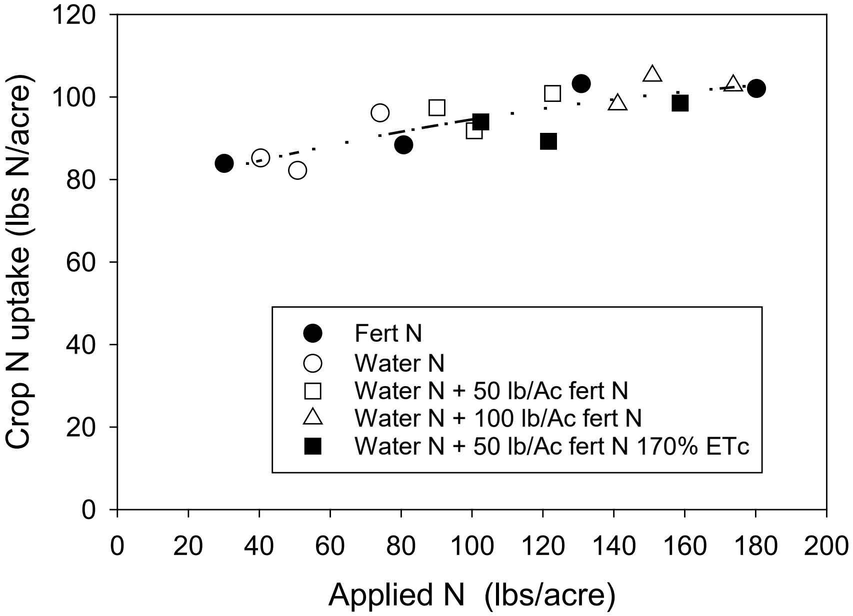


Figure 17. Effect of applied nitrogen on N content on crop N uptake (trial 4, fall harvest).

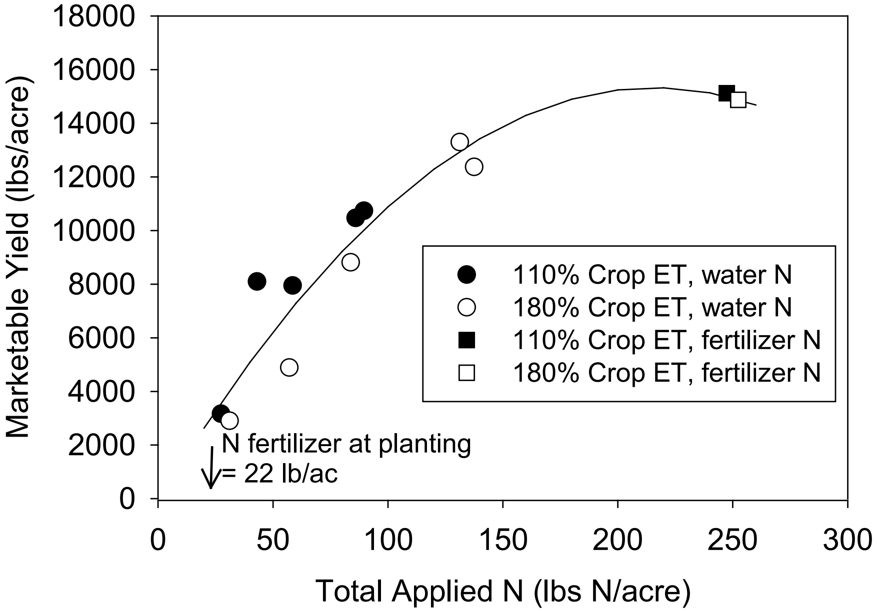


Figure 18. Effect of applied nitrogen on marketable yield of broccoli (trial 5, fall harvest).

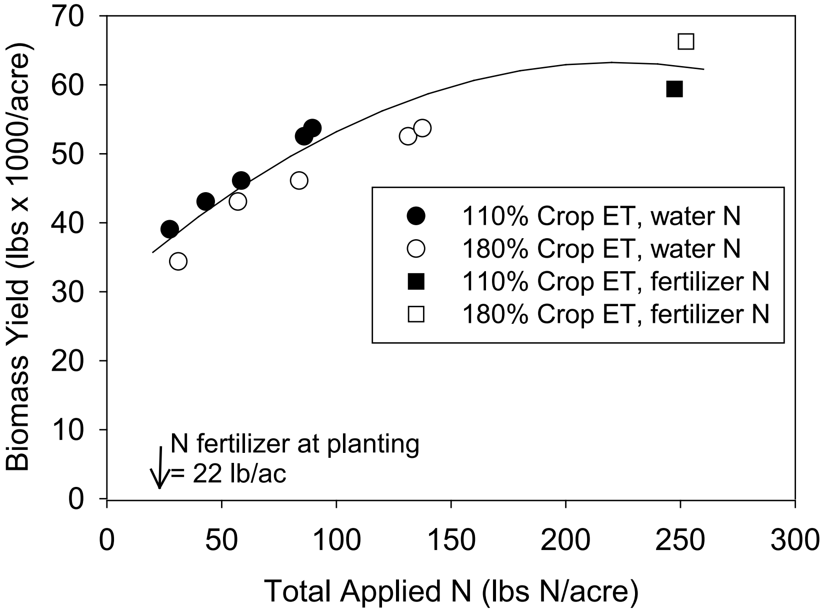


Figure 19. Effect of applied nitrogen on biomass yield of broccoli (trial 5, fall harvest).

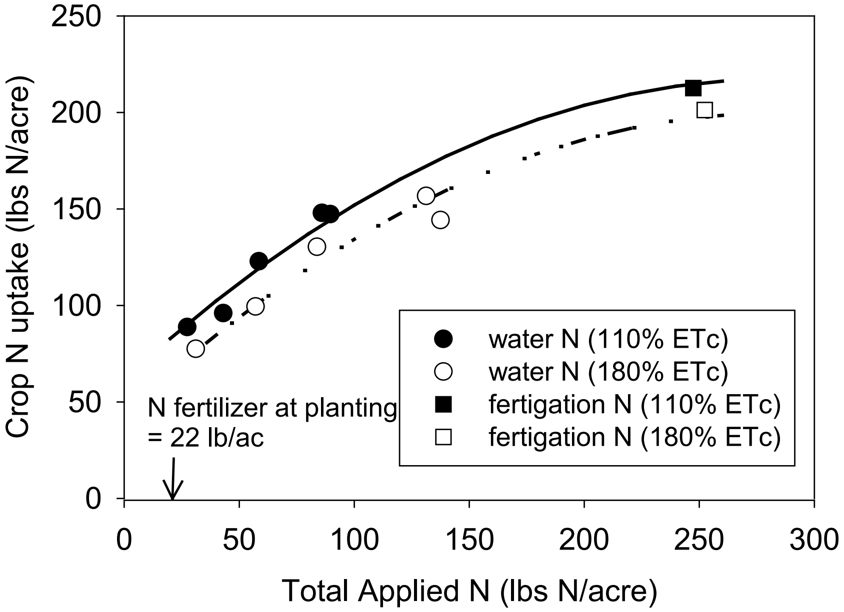


Figure 20. Effect of applied nitrogen N uptake of broccoli (trial 5, fall harvest).

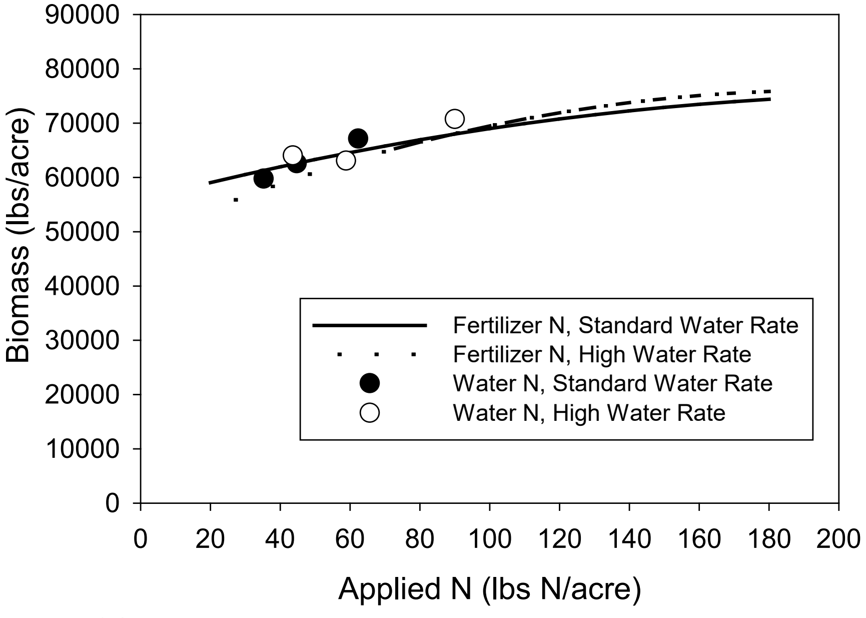


Figure 21. Lettuce biomass yield response to N in water and fertilizer N at standard and high water rates. Regression curves were fit to data from treatments receiving only fertilizer N. Symbols represent the means of the water N treatments.

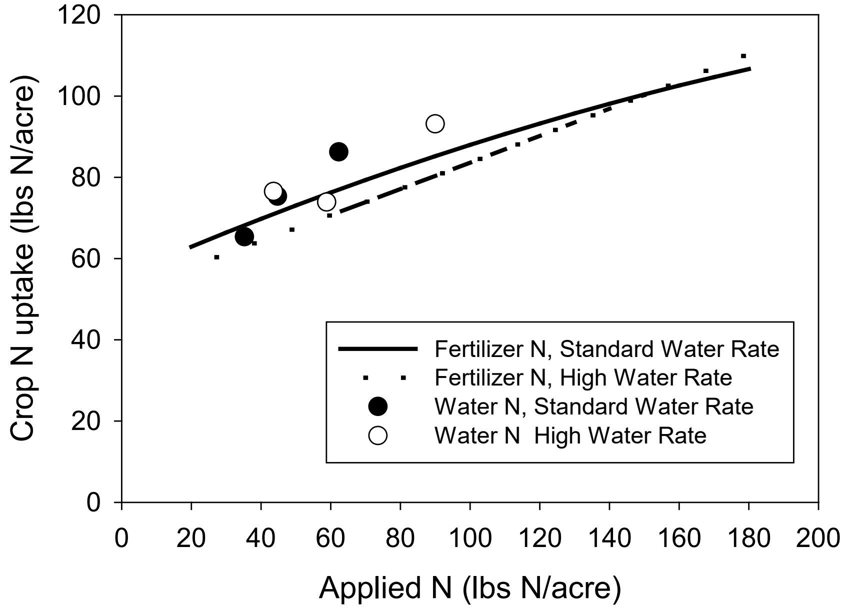


Figure 22. N uptake by lettuce from water and fertilizer sources of N at standard and high water rates. Regression curves were fit to data from treatments receiving only fertilizer N. Symbols represent the means of the water N treatments.

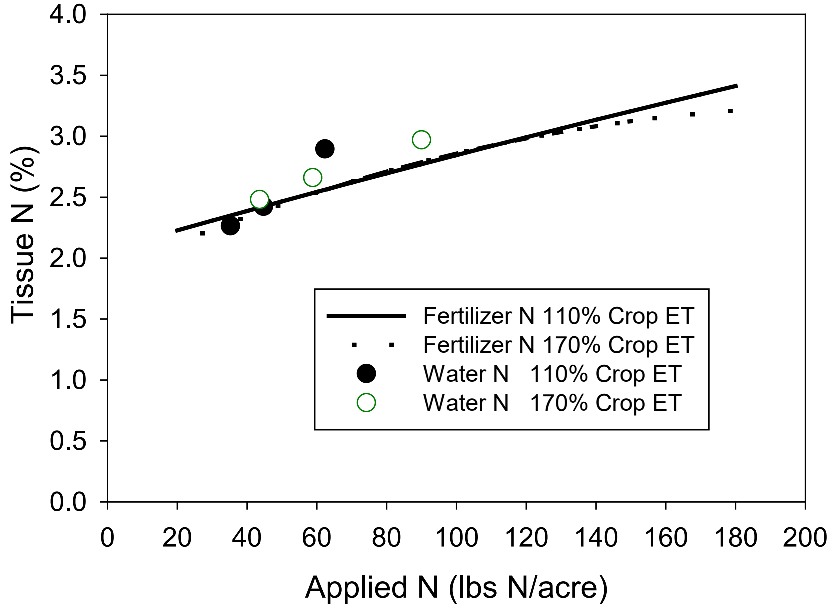


Figure 23. N content of lettuce leaf tissue for water and fertilizer sources of N at standard and high water rates. Regression curves were fit to data from treatments receiving only fertilizer N. Symbols represent the means of the water N treatments.

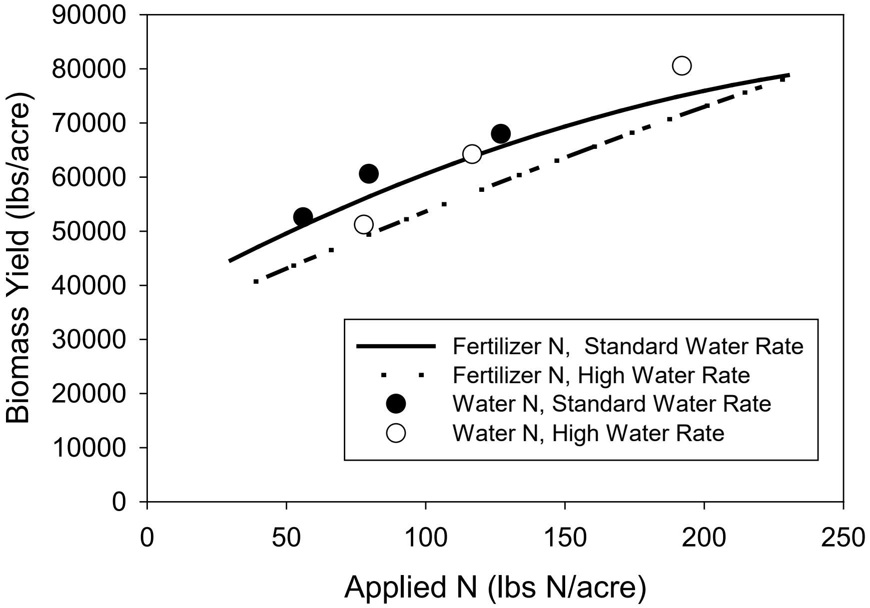


Figure 24. Broccoli biomass yield response to N in water and fertilizer N at standard and high water rates. Regression curves were fit to data from treatments receiving only fertilizer N. Symbols represent the means of the water N treatments.

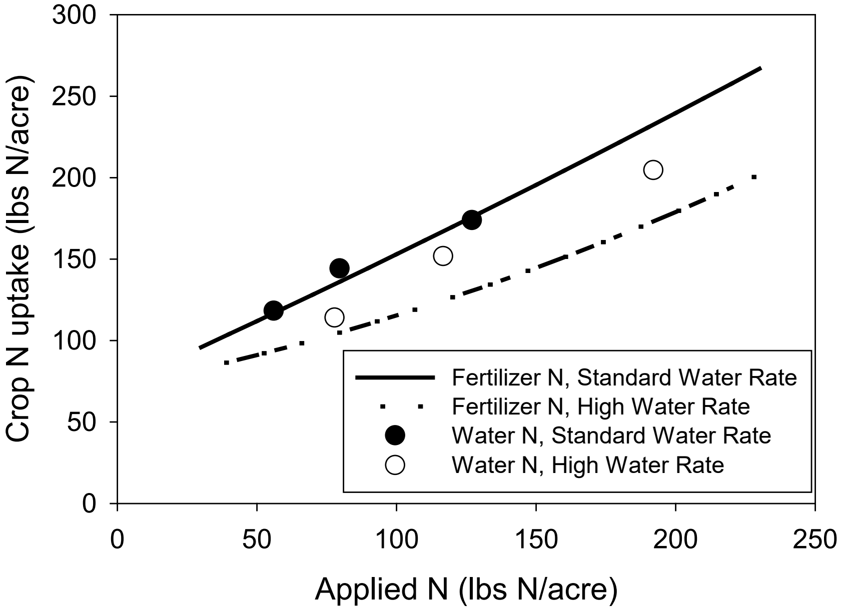


Figure 25. N uptake by broccoli from water and fertilizer sources of N at standard and high water rates. Regression curves were fit to data from treatments receiving only fertilizer N. Symbols represent the means of the water N treatments.

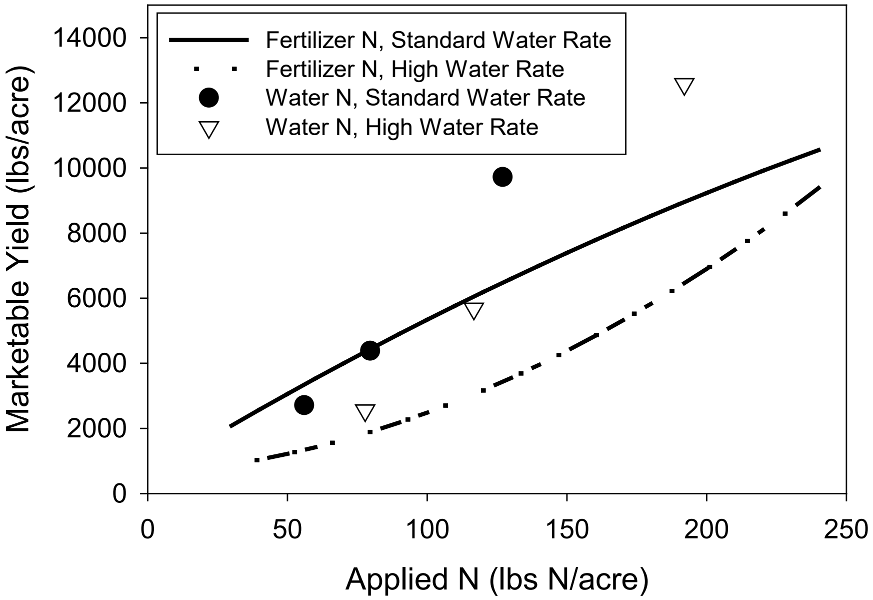


Figure 26. Marketable yield of broccoli in response to water and fertilizer sources of N at standard and high water rates. Regression curves were fit to data from treatments receiving only fertilizer N. Symbols represent the means of the water N treatments.

H. Project Impacts

This project may potentially help vegetable growers use nitrogen fertilizer more efficiently by taking credit for background levels of N that are present in their irrigation water. The results of 7 replicated field trials conducted in lettuce and broccoli during the past 3 years conclusively demonstrated that the N in irrigation water has the same potential benefit for these crops as fertilizer sources of nitrogen. Since many wells in the vegetable production regions of the central coast have concentrations of nitrate in range of 20 to 40 ppm N, growers could potentially reduce fertilizer applications by 30 to 60 lbs N/acre per lettuce crop without risking yield loss. Taking credit for N in irrigation water would reduce costs for growers and also minimize nitrate loading to the aquifer. Beyond demonstrating the feasibility to reduce N applications, this project has provided guidelines to growers on how to accurately account for N in irrigation water when developing a nutrient budget. These guidelines were provided in a peer reviewed journal article, trade and newsletter articles, oral presentations, as well as developed into a spreadsheet application that is being incorporated into the CropManage irrigation and nutrient management decision support tool.

I. Outreach Activities

Oral presentations of the project were made at the annual UCCE Irrigation and Nutrient Meeting in 2014, 2015 and 2016, as well as the California Plant and Soil Conference and the American Society of Agronomy meetings. A field day was also held in conjunction with the California Leafy Green Research Board to view the broccoli trial in October 2015. Additionally, results were presented at CCA nutrient management trainings held in San Luis Obispo, in 2015. Other presentations on trial results are summarized in Table 7. A total of 1077 attended the 19 presentations given to date. Copies of presentations and reports were requested by and provided to the Central Coast Regional Water Quality Control Board.

Table 15. Summary of outreach activities (2014-2016).

#	Date	Meeting name	Presentation Topic	Sponsors/Co-Sponsors	Location	Attendance
1	2/12/2014	UC Irrigation and Nutrient Meeting	Fertilizer value of Ambient N in irrigation water	UCCE Monterey	Salinas CA	105
2	3/6/2014	Nutrient Management Seminar	Irrigation Strategies for Efficiently Using Nutrients	CDFA/CCA	Salinas CA	40
3	3/7/2014	Nutrient Management Seminar	Irrigation Strategies for Efficiently Using Nutrients	CDFA/CCA	Salinas CA	41
4	3/18/2014	CLGRB meeting	Evaluation of best irrigation and nutrient management practices to safeguard water quality	CLGRB	Coalinga CA	76
5	4/24/2014	Monterey County Castroville Seawater Intrusion Project Operations meeting	Fertilizer Value of Ambient N in Irrigation Water for Vegetable Production	Monterey County Pollution Control Agency	Marina CA	35
6	10/7/2014	Califorinia Leafy Green Research Board Meeting	Fertilizer value of ambient N for vegetable production	CLGRB	Salinas CA	20
7	10/29/2014	CDFA-FREP annual conference	Fertilizer value of ambient N for vegetable production	CDFA-FREP	Modesto CA	140
8	11/3/2014	Agronomy Society of America Meetings	Fertilizer value of ambient N for vegetable production	ASA-CSSA-SSSA	Long Beach CA	45
9	2/5/2015	Cal ASA Plant and Soil Conference	Fertilizer Value of Ambient N in Irrigation Water for Vegetable Production	Cal ASA	Modesto CA	70
10	2/19/2015	UC Irrigation and Nutrient Meeting	Fertilizer Value of Ambient N in Irrigation Water for Vegetable Production	UCCE Monterey	Salinas CA	70
11	3/17/2015	California Leafy Greens Research Board	Fertilizer Value of Ambient N in Irrigation Water for Vegetable Production	CLGRB	Coalinga CA	80
12	10/7/2015	California Leafy Greens Research Board	Fertilizer Value of Ambient N in Irrigation Water for Vegetable Production	CLGRB	Salinas CA	30
13	2/11/2016	San Benito Irrigation and nutrient meeting	Irrigation strategies for efficiently using nutrients in vegetables	San Benito Water Distict	Hollister CA	40
14	2/17/2016	UC Irrigation and Nutrient Meeting	Fertilizer Value of Ambient N in Irrigation Water for Vegetable Production	UCCE Monterey	Salinas CA	70
15	3/28/2016	Central Coast Groundwater Coalition Grower Meeting	Irrigation strategies for efficiently using nutrients in vegetables	Central Coast Groundwater Coalition	Santa Maria CA	30
16	3/31/2016	Central Coast Groundwater Coalition Grower Meeting	Irrigation strategies for efficiently using nutrients in vegetables	Central Coast Groundwater Coalition	Prunedale CA	30
17	7/28/2016	2016Irrigation and Nutrient Management Meeting for Berry and Vegetable Crops.	Fertilizer value of nitrate in irrigation water	UCCE Ventura	Port Hueneme, CA	70
18	11/2/2016	Central Coast Nutrient Seminar	Row Crops and Current Research with Nitrogen	Western Plant Health Association	Paso Robles CA	45
19	12/5/2016	Vegetable crop continuing conference	Fertilizer Value of Nitrogen in Irrigation Water for Coastal Vegetable Production	UC Davis VRIC and Plant Sciences Dept.	Davis CA	40

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J. Fact Sheet

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

CDFA Agreement 12-0455-SA

Project leaders:

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

Project period: 2013-2016

Location Monterey County, Salinas CA

Highlights

- Replicated trials in lettuce and broccoli demonstrated that nitrate in ground water has the same value as fertilizer sources of N.
- Growers can save money and reduce nitrate loading by crediting nitrate in groundwater when developing nutrient budgets.
- The results of these trials were extensively outreached to the vegetable industry through trade journal articles and oral presentations.

Introduction

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. 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. The purpose of this project was to develop information and guidelines for utilizing ambient N in irrigation water for lettuce and broccoli, the main crops produced in this region.

Methods/Management

A total of 7 replicated field trials were conducted in the Salinas Valley from 2013-15. Three trials focused on determining the efficiency of lettuce and broccoli to recover N from irrigation water, as affected by concentration and irrigation efficiency. The remaining trials examined the practical contribution of irrigation water N to crop fertility under a range of typical irrigation and N fertigation regimes. Crops were drip irrigated after establishment using water of nitrate concentrations ranging from 2 to 44 ppm N. Water-powered injection pumps were used to enrich all drip applied water to target nitrate concentrations. These water treatments were compared to an unfertilized control and standard fertilizer treatments. Crop biomass yield and N uptake were compared among treatments using analysis of variance statistics and regression analysis.

This project also had a strong outreach component, including newsletter and trade journal articles, oral presentations, and online resources. A summary of the project was published in California Agriculture Journal (http://ucanr.edu/repositoryfiles/ca2017a0010-165364.pdf). 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.

Findings

The results of field trials conducted during 2013-2015 demonstrated that N in irrigation water has fertilizer value for both shallow (lettuce) and deep (broccoli) rooted vegetables, even when the N concentration in the water was low (12 to 14 ppm N). The trials also showed that the volume of water applied did not affect the crop recovery rate of N from water more than from fertilizer, suggesting that it was reasonable to credit all the N applied in water as having fertilizer value to the crop. These results were attained under well-managed drip irrigation with a high application uniformity and frequent irrigations so that irrigation volumes were small, which likely minimized leaching losses. It is possible that under poor water management or less efficient irrigation methods (eg. furrow), recovery of N would be less than was reported in these trials. Additionally, the N water treatments commenced after crop establishment when crop ET and N update was substantially higher than during germination. The trials also showed that the source of N (NH_4 *vs* NO_3) did not affect crop recovery (Fig. 4). Presumably NH_4 would quickly transform to NO_3 when added to the soil.

Although the results of these experimental trials confirmed that growers can confidently take credit for background levels of nitrate in the irrigation water, they should still be cautious when implementing this practice. Experimenting on fields where the water source is known to have a consistently high concentration of nitrate but is not excessively high in salts is recommended. Drip provides better control of irrigation volumes than sprinklers and furrow systems, which may minimize excessive leaching, and also offer more opportunities for fertigating N to correct observed deficiencies. Because the crop water use is low during the first weeks after planting, it is also reasonable to wait until after establishment to take credit for the nitrogen supplied by the irrigation water. Soil nitrate levels should be monitored after crop establishment to determine if the soil has a sufficient supply of N. If using multiple water sources for a crop, the nitrate concentration of the blended water needs to be determined in samples collected at the field. Finally, applied water volumes need to be accurately monitored to estimate the amount of N that was applied through the irrigation water.

Pump and Fertilizer: factoring nitrogen from irrigation water into nutrient budgets.

Michael Cahn, Tim Hartz, Richard Smith, Laura Murphy

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 under the current ‘Ag Order’ that was adopted by the Central Coast Region Water Quality Control Board in 2012. The Ag Order requires tier 2 and 3 growers who produce vegetable and berry crops to report the total amount of nitrogen applied to crop land, including N contained in irrigation water. Baseline numbers from the first two years of reporting on the Central Coast clearly showed that a majority of vegetable producers applied significantly more nitrogen than their crops took up.

Water quality regulators would like growers to take proactive steps to reduce nitrogen inputs to their crops. One way many growers could make significant reductions in their use of fertilizer N is by off-setting their nitrogen fertilizer rates by a portion of the N applied through their irrigation water. The term “pump and fertilize” has been used to describe this practice because conceptually a grower is pumping water and using the water as fertilizer for the crop. The benefit for the grower is lower fertilizer costs, and the benefit for the environment is reducing nitrate loading to groundwater.

In the Salinas Valley, the nitrate concentration of water pumped from agricultural wells averages more than 20 ppm N. This N concentration would translate to 37 lbs of N per acre for a lettuce crop receiving 8 inches of irrigation water. A significant number of wells have nitrate-N concentrations in the range of 30 to 50 ppm, and the amount of N that potentially could be applied to crops by irrigating with this water could be as high as 55 to 90 lbs per acre. Since most lettuce crops take up 130 to 150 lbs of N per acre, high nitrate water could substitute for one third to half of the fertilizer N normally needed to produce a crop.

Despite the potential benefits of implementing “pump and fertilize,” adoption by growers has been slow. One reason is due to doubts that the nitrate in irrigation water is completely available to crops. Chemically speaking, nitrate in fertilizer and ground water are exactly the same. Nevertheless, growers are concerned that N concentrations in high nitrate water may still be too low to be absorbed by crop roots. Fertilizer N applications usually boosts the N concentration of the soil water to levels much higher than are found in irrigation water.

Another reason that growers are reluctant to account for the N in irrigation water is because they are uncertain about how much fertilizer credit to take if water is applied to leach salts. Some growers have also expressed concern that the nitrates significantly increase the salinity of water, making it less beneficial to their crops. Finally, growers who use multiple wells to irrigate their fields have difficulty estimating the average N concentration of the irrigation water applied to their crops.

Research trials

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. During the past 3 years we conducted replicated field trials to evaluate how much of the nitrate in irrigation water could be taken up by head lettuce (*cv.* Telluride) and broccoli (*cv.* Patron). Crops were seeded in two rows on 40-inch wide beds, and germinated with sprinklers. The only N applied at planting was from an anti-crustant application ranging from 17 to 22 lbs N/acre. Crops were drip irrigated after establishment using water of nitrate concentrations ranging from 2 to 44 ppm N. Water-powered injection pumps were used to enrich all drip applied water to target nitrate concentrations. Injected NO_3-N was a blend of $Ca(NO_3)_2$ and $NaNO_3$ to maintain the cation balance in the water. These water treatments were compared to an unfertilized control and standard fertilizer treatment (150 and 225 lbs N/acre AN20 for lettuce and broccoli, respectively). In addition, a water treatment dominated by NH_4-N was included in the trials to simulate the N composition of recycled water. To observe the interaction of irrigation efficiency and crop nitrogen recovery, each N treatment was evaluated at two rates of applied water: 1. Standard water rate of 110% of crop ET 2. High water rate of 160% to 180% of crop ET, which corresponded to a 40% to 50% leaching fraction.

A second set of field trials directly compared crop N recovery from irrigation water and fertilizer. Irrigation water with concentrations of 14, 25, and 44 ppm NO_3-N were compared with fertigation applications of AN20 of seasonal totals equal to 0, 20, 60, and 150 lbs N/acre in lettuce and 0, 40, 80, and 200 lbs N/acre for broccoli.

Treatments in all trials were replicated 4 times and individual plots measured 4 beds × 40 ft. All trials were harvested when the highest fertilizer treatment reached commercial maturity. Above ground fresh and dry biomass yield were evaluated in the center two beds of the plots. Whole plant N content was determined so that crop N uptake could be estimated. Crop N uptake was plotted against N applied in the water and fertilizer N treatments. The amount of N applied in the water treatments was calculated by the equation:

Applied N (lbs/acre) = applied water (inches) × N concentration of water (ppm N) × 0.23

Applied N from the water treatments increased as the applied water amounts and concentration of N in the water increased.

Results

Results of the lettuce trial demonstrated that the concentration of nitrogen in the irrigation water significantly affected plant size, N content of tissue, biomass yield (data not presented) and confirmed that a significant portion of the N in the irrigation water was taken up by the crop (Fig. 1). The crop was able to utilize concentrations of NO_3-N as low as 12 ppm in the irrigation water. Similar results were also observed in the broccoli trial (Fig. 2). As shown by the regression curves fit to the data, crop N uptake from irrigation water increased as the concentration of N in water increased. The fertilizer treatment indicated that the relationship between N uptake and applied N would likely level off at high N concentrations.

The N uptake from the water treatments in lettuce was similar for high and standard water rates, indicating that the volume of water applied did not affect the recovery of N (Fig. 1) and that all of the applied water could be credited as having N value for the crop. For broccoli, N uptake was lower under the high water rate (180% ET) than the standard water rate (110% ET). However, the recovery of N from the standard fertilizer treatment was also less under the high water rate (Fig. 2).

The source of N in the irrigation water (NH_4 *vs* NO_3) had no significant effect on N recovery by the crop (Fig. 3). Presumably NH_4 would quickly transform to NO_3 when added to the soil. Nitrate did boost the salinity of water, but the amount was small: approximately 0.07 dS/m for each 10 ppm increase in Nitrate-N concentration. Hence, water with a 45 ppm NO_3-N concentration would have a boost in electrical conductivity of only 0.31 dS/m.

The second set of trials confirmed that crop recovery of N from irrigation water and fertilizer was similar in lettuce (Fig. 4) and in broccoli (Fig. 5). The symbols in both figures represent the mean N uptake response from the water treatments and the regression curves were fit to the N uptake response to the fertilizer treatments. The fact that most of the water treatments are equal to or above the regression line demonstrated that the crop N uptake from the water was equal or greater than from fertilizer sources of N. Similar to the previous trials, crops were able to recover N from water with concentrations of nitrate as low as 14 ppm N. N recovery was similar under high and standard water rates for lettuce but as found in the earlier trial with broccoli, crop N recovery declined for both the fertilizer and the water sources of N under the high water rate (Fig. 5).

Implications for reducing N inputs

The results of these field trials demonstrated that N in irrigation water has fertilizer value for both shallow (lettuce) and deep (broccoli) rooted vegetables, even when the N concentration in the water was low (12 to 14 ppm N). The trials also showed that the volume of water applied did not affect the crop recovery rate of N from water more than from fertilizer, suggesting that it is reasonable to credit all the N applied in water as having fertilizer value to the crop. These results were attained under well-managed drip irrigation with a high application uniformity and frequent irrigations so that irrigation volumes were small, which likely minimized leaching losses. It is possible that under poor water management or less efficient irrigation methods (eg. furrow), recovery of N would be less than was reported in these trials.

Although the results of these experimental trials confirmed that growers can confidently take credit for background level of nitrate in the irrigation water, one should still be cautious when implementing this practice. Experimenting on fields where the water source is known to have a consistently high concentration of nitrate but is not excessively high in salts is recommended. Drip provides better control of irrigation volumes than sprinklers and furrow systems, which may minimize excessive leaching, and also offer more opportunities for fertigating N to correct observed deficiencies. Because the crop water use is low during the first weeks after planting, it is also reasonable to wait until after establishment to take credit for the nitrogen applied in irrigation water. Soil nitrate levels should be monitored after crop establishment to determine if the soil has a sufficient supply of N. If using multiple water sources for a crop, the nitrate concentration of the blended water needs to be determined in samples collected at the field. Finally, applied water volumes need to be accurately monitored to estimate the amount of N that was applied through the irrigation water.

With water quality regulations continuing to become stricter for agriculture, it makes sense for growers to start implementing practices that can both lower farming costs and are beneficial for the environment. By accounting for the nitrate in irrigation water and using the soil nitrate quick test to monitor soil N levels, growers may be able to make significant progress in reducing the amount of fertilizer nitrogen needed to produce their crops, and demonstrate that they are addressing water quality concerns.

Acknowledgements

We thank Sharon Benzen and David Lara of the USDA-ARS in Salinas, CA for assistance with the field trials. This project was funded by a grant from the California Department of Food and Agriculture’s Fertilizer Research and Education Program (FREP) and the Fertilizer Inspection Advisory Board.

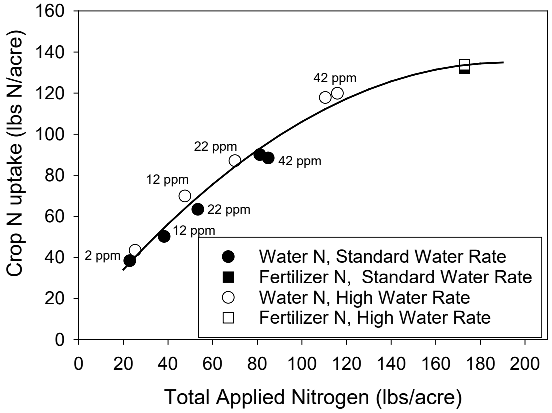

Figure 1. N uptake by lettuce from water and fertilizer sources of N at standard (110% ET) and high water rates (160% ET). Symbols represent the mean N uptake of water and fertilizer treatments. N concentration of water treatments is displayed next to the symbols.

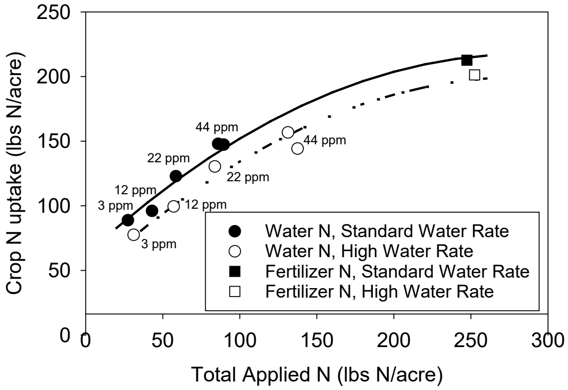

Figure 2. N uptake by broccoli from water and fertilizer sources of N at standard (110% ET) and high water rates (180% ET). Symbols represent the mean N uptake of water and fertilizer treatments. N concentration of water treatments is displayed next to the symbols.

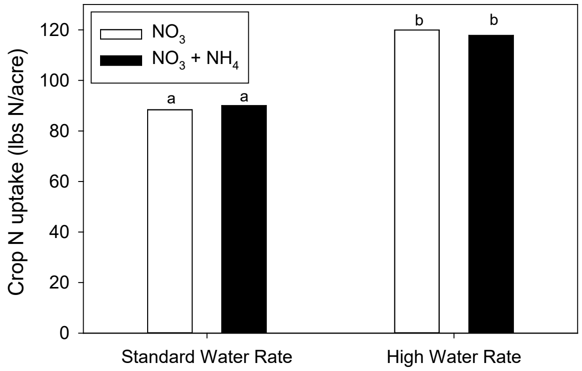

Figure 3. N uptake by lettuce from water with nitrate and ammonium sources of N at standard (110% ET) and high water rates (160% ET).

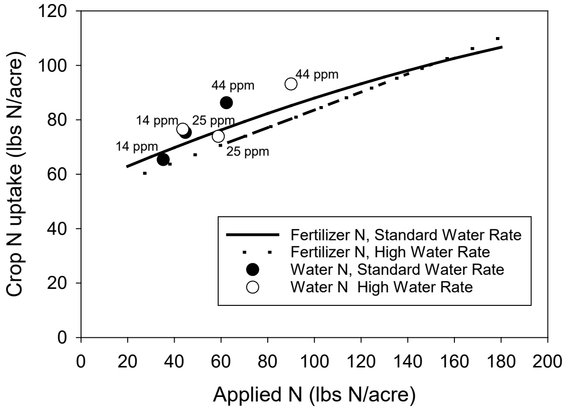

Figure 4. N uptake by lettuce from water and fertilizer sources of N at standard (110% ET) and high water rates (170% ET). Regression lines represent N uptake response to fertilizer treatments. Symbols represent average N uptake from water treatments. N concentration of water treatments is displayed next to the symbols.

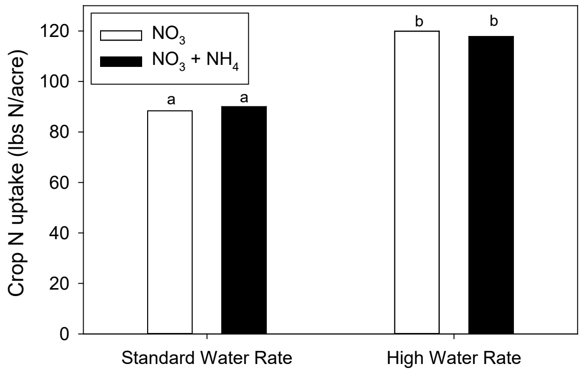

Figure 3. N uptake by lettuce from water with nitrate and ammonium sources of N at standard (110% ET) and high water rates (160% ET).

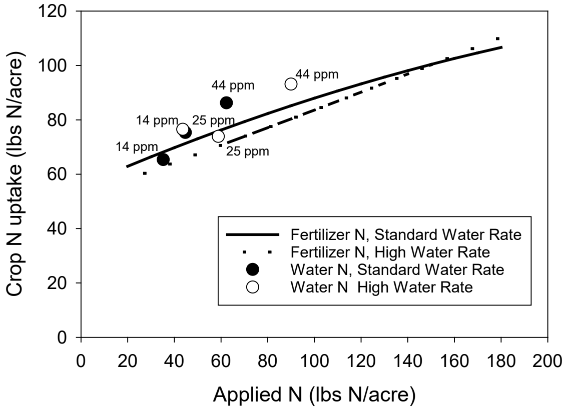

Figure 4. N uptake by lettuce from water and fertilizer sources of N at standard (110% ET) and high water rates (170% ET). Regression lines represent N uptake response to fertilizer treatments. Symbols represent average N uptake from water treatments. N concentration of water treatments is displayed next to the symbols.

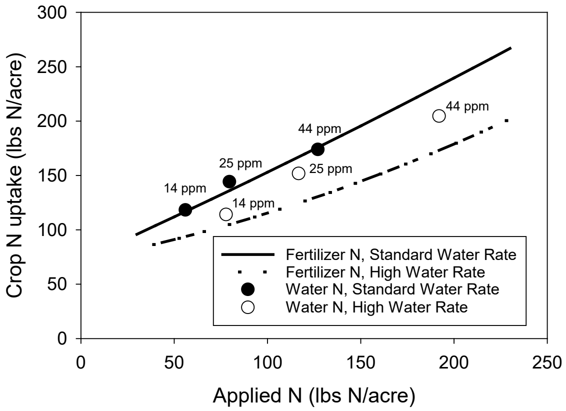

Figure 5. N uptake by broccoli from water and fertilizer sources of N at standard (110% ET) and high water (180% ET) rates. Regression lines represent N uptake response to fertilizer treatments. Symbols represent average N uptake from water treatments. N concentration of water treatments is displayed next to the symbols.